ECONOMIC ANALYSIS OF AN ARCTIC ICEBREAKING TANKER TRANSPORTATION SYSTEM: NUCLEAR VS. FOSSIL

Thomas J. Porter

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Economic Analysis of an Arctic Icebreaking Tanker Transportation System: Nuclear vs. Fossil		5. TYPE OF REPORT & PERIOD COVERED THESIS
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas J. PORTER		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Pennsylvania State University		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS NAVPGSCOL CODE 031		12. REPORT DATE NOV 77
		13. NUMBER OF PAGES 102
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASS
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

A. Approved for Public Release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Arctic Icebreaking; Economic Analysis; Tanker Transportation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The author compares the movement of crude oil from the North Shore using conventional fossil fueled tankers vs. nuclear powered ice-breakers including transshipment at an ice-free port on the east coast. The study points out the economic competitiveness of the nuclear icebreaking tanker transportation system.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The Pennsylvania State University

The Graduate School

Department of Nuclear Engineering

Economic Analysis of an Arctic Icebreaking Tanker Transportation System: Nuclear vs. Fossil

A Paper in

Nuclear Engineering

by

Thomas J. Porter

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

November 1977

TABLE OF CONTENTS

	Page
LIST OF TABLES	iii
LIST OF FIGURES	iv
ACKNOWLEDGMENTS	v
I. INTRODUCTION	1
II. CONCLUSIONS	4
III. DESCRIPTION OF THE TRANSPORTATION SYSTEM	7
IV. ECONOMIC CRITERIA	21
V. ECONOMIC ANALYSIS: REFERENCE CASE	33
VI. ECONOMIC ANALYSIS: SENSITIVITY STUDIES	66
VII. SUMMARY AND RECOMMENDATIONS	84
BIBLIOGRAPHY	86
APPENDIX A: COMPUTER CODE FOR NUCLEAR SYSTEM	88
APPENDIX B: COMPUTER CODE FOR FOSSIL SYSTEM	96

LIST OF TABLES

Table		Page
2-1	System Required Freight Rate	4
3-1	Ice Related Delays	14
3-2	Ship Characteristics	18
5-1	Economic Data for Reference Case	34
5-2	Voyage Times--Smith Bay to FROST	35
5-3	Ship Availability--Fossil Fueled Icebreaking Tanker	36
5-4	Ship Availability--Nuclear Powered Icebreaking Tanker	37
5-5	Voyage Data	38
5-6	Icebreaking Tanker Construction Cost	43
5-7	Pre-Payment Schedule--Fossil Fueled Icebreaking Tanker	44
5-8	Pre-Payment Schedule--Nuclear Powered Icebreaking Tanker	45
5-9	Predelivery Costs--Icebreaking Tankers	47
5-10	Construction Costs for Smith Bay Loading Terminal	48
5-11	Total Capital Costs for Arctic Terminals	50
5-12	Summary of Projected Annual Icebreaking Tanker Operating Expenses	55
5-13	Summary of Projected Annual Terminal Operating Expenses	57
5-14	Core Data	58
5-15	Nuclear Fuel Economic Data	59
5-16	Surface Tanker Contribution to System RFR	63
5-17	System Required Freight Rates--Reference Case	64

LIST OF FIGURES

Figure		Page
3-1	Proposed Trade Route for Nuclear Powered Icebreaking Tanker Transportation System	10
4-1	Division of Revenue	29
5-1	RFR Calculation Schematic Diagram	41
6-1	Effects of Capital Cost Escalation on RFR	68
6-2	Effects of Construction Differential Subsidy on RFR	70
6-3	Effects of Nuclear Propulsion Plant Cost on RFR	71
6-4	RFR Variation Due to Terminal Construction Cost	73
6-5	RFR as a Function of Nuclear Fuel Cost	74
6-6	RFR as a Function of the Nuclear Fuel Cost Escalation Rate	75
6-7	Effects of Varying the Bunker C Fuel Oil Cost on RFR	77
6-8	RFR as Affected by the Bunker C Fuel Oil Cost Escalation Rate	78
6-9	Effects of the Time of Ship Amortization on RFR	79
6-10	Effects of Varying Bank or Bond Interest Rate on Tanker RFR	81
6-11	Variation of Debt to Total Capital Ratio and Its Effect on Tanker RFR	83

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. Warren F. Witzig for his guidance, helpful criticism, and encouragement; and to Dr. Gordon E. Robinson for his objective appraisal and technical review of the manuscript. Recognition should also be given to Dr. Zelvin Levine and Mr. C. W. Parker of the United States Maritime Administration; Mr. Richard P. Voelker, Vice President, ARCTEC, Incorporated; Mr. A. O. Winall, Manager of Commercial Ship Marketing, Newport News Shipbuilding; Mr. R. W. Dickinson, Manager, Maritime Reactors; Mr. S. H. Esleeck, Manager, Marine Sales (Nuclear Division) and Mr. R. E. Witham, Manager, Marine Sales (Industrial and Marine Division) of the Babcock and Wilcox Company; and to Mr. J. P. Jones and Mr. P. Callahan of the Mobil Shipping and Transportation Company for the invaluable information and personal assistance they supplied. Also, to the United States Navy for providing the opportunity and financial support for the author to conduct his studies.

I. INTRODUCTION

Background

The ongoing energy crisis in the United States has highlighted a critical need for accelerated research and development of all potential energy sources in conjunction with an ambitious development of all available domestic energy reserves. Within the context of expanding the utilization of our domestic energy resources there is an entire spectrum of possibilities. This research has addressed only one aspect of this enormously complex problem, specifically, a system capable of transporting petroleum reserves from the Alaskan North Slope to the United States East Coast.

Presently the only method for transporting Alaskan crude oil to the contiguous United States is via the trans-Alaskan pipeline from Prudhoe Bay to Valdez and ultimately to West Coast refineries via conventional tankers, or East Coast refineries via the Panama Canal. This paper details the economics of an adjunct system which would provide a means of supplying East Coast refineries from the yet untapped estimated five billion barrels of Alaskan oil from the National Petroleum Reserve in Alaska (formerly designated the Naval Petroleum Reserve Number 4). This area is a leading contender for future exploitation and was, therefore, chosen for this study.

A subsidiary of Husky Oil, Ltd. will receive $190 million in fiscal 1978 to continue exploratory drilling in the above area. The operation will consist of drilling six exploratory oil wells, three natural gas wells, and two drilling pads for use in a future phase of development. The latest estimate by the Federal Energy Administration

predicts there is up to five billion barrels of oil and 14.3 trillion cubic feet of gas in the area[1].

A recent Maritime Administration, Newport News Shipbuilding, ARCTEC, Inc. and Babcock and Wilcox study[2] indicates that icebreaking tankers are technically feasible for operation from Alaska via the Northwest Passage to the East Coast of the United States. This paper is predicated on the above premise and thus concentrates on analyzing the economics of such a system.

Objectives and Methodology

The objectives of this study are twofold:

1. To investigate the economic viability of an arctic icebreaking tanker transportation system capable of transporting Alaskan crude oil to the East Coast of the United States.
2. To economically compare two competing arctic icebreaking tankers, i.e., nuclear powered versus fossil fueled.

In support of the stated objectives, this study examines a transportation system with the following major components:

1. Loading terminal in Alaska
2. Icebreaking tanker fleet
3. Mobile transshipment terminal
4. Conventional surface tanker fleet
5. Terminal facilities on the U.S. East Coast.

Of the latter components, only the first three are unique to this system since existing surface tankers could be chartered to transport

the oil from the mobile transshipment terminal near the edge of the ice to existing unloading facilities on the East Coast. Accordingly, the major emphasis of this study concentrates on the northern terminal, the icebreaking tankers, and the mobile transshipment terminal. Conceptual design work on these components was beyond the scope of this study. The basic design configurations developed by Newport News Shipbuilding[2], with major modifications to the tankers' power plants, were utilized in this study.

This economic analysis is not adequate for the final decision to commit billions of dollars to a project of this magnitude. However, it is intended to be sufficiently accurate to establish whether future interest and effort in this area is warranted.

The "measure of merit" chosen for the economic evaluation is the Required Freight Rate (RFR). This criterion, which is widely used when revenues are unknown, implies that the best ship (or system) is one offering the services at the lowest unit cost to the customer, while returning to the owner a reasonable level of profitability after tax[3]. The definition for this rate is:

$$\text{RFR} = \frac{\text{Average Annual Cost}}{\text{Average Annual Cargo Units Carried}}$$

Furthermore, this study utilizes a Discounted Cash Flow approach in the economic analyses. The detailed approach and methodology is described in Chapter IV, Economic Criteria.

II. CONCLUSIONS

This study concludes that an icebreaking tanker transportation system designed to move petroleum reserves from the Alaskan North Slope to the East Coast of the United States is economically feasible; and furthermore, that a nuclear powered icebreaking tanker is superior to a fossil fueled icebreaking tanker for this arduous mission voyage. Table 2-1 summarizes the results of the detailed analysis contained in Chapter V of this paper.

Table 2-1

System Required Freight Rate ($/BBL)

	System RFR
Icebreaking Tanker System (Nuclear)	9.35
Icebreaking Tanker System (Fossil)	10.30
Pipeline (Prudhoe-Valdez); Conventional Surface Tanker via Panama Canal to U.S. East Coast System	15.00

Table 2-1 shows that, while both icebreaking tanker systems are economically superior to the pipeline/surface tanker system, the nuclear icebreaking tanker system enjoys an economic advantage of approximately 9% over its fossil fueled counterpart. This modest advantage gains added significance when it is pointed out that these reference case study figures were developed assuming icebreaking tanker fleets of

equal size. In fact, the fossil system requires two additional ice-breaking tankers to deliver the annual design steady state system throughput of 730 million barrels. The requirement for two additional tankers adds about 7.8% to the fossil tanker RFR. Thus, it appears that the nuclear system has a true economic advantage of approximately 17%.

The treatment of operating cost escalation has a major impact on the relative importance of capital costs. In fact, when operating costs are not escalated, the two tanker systems are at a virtual economic standoff. When comparing the economics of a highly capital intensive system (nuclear) with an operating cost intensive system (fossil), it is important to consider the effects of both operating cost and capital cost escalation to yield a truly valid comparison. This is necessary because the combination of "present value" calculations and cost escalation has different effects on capital costs and operating costs. Systems with a high acquisition cost/operating cost ratio may appear better than systems with a low ratio if operating costs are escalated, but appear worse than those same systems if operating costs do not escalate[4].

The transportation system evaluated in this study can be realized using existing U.S. technology, facilities and methods. No major technical breakthroughs are required for system implementation.

It is recognized that, as is the case with any economic assessment, one can argue and debate many of the input variables upon which these conclusions are based. However, the estimates utilized herein are consistent with previous analyses of this type, and in all cases, criteria of engineering and economic conservation prevailed.

Development of the nuclear icebreaking tanker and concurrent development of the associated peripheral systems can provide significant improvement in U.S. energy self-sufficiency and the balance of trade.

III. DESCRIPTION OF THE TRANSPORTATION SYSTEM

General

The transportation system described in this chapter is comprised of the following components:

1. Northern loading terminal in Alaska
2. Icebreaking tanker fleet
3. Mobile transshipment terminal
4. Conventional surface tanker fleet to transport the crude oil to existing U.S. East Coast refineries.

The contribution of each of these components to the system Required Freight Rate must be evaluated. The transportation system being economically evaluated in this study is very similar in conceptual design to the system described in reference 2. Therefore, much of the information in this chapter has been summarized from that reference.

Northern Terminal

Ideally, the northern loading terminal should be situated as close as practicable to the source of cargo oil. This naturally would minimize many construction costs such as digging pipeline trenches, laying pipelines, etc. Since this study assumes that the national petroleum reserve in Alaska is the potential source of oil, Smith Bay, Alaska, approximately midway between Prudhoe Bay and Point Barrow, has been selected as the site for the northern terminal. It is important to note that this choice is by no means the only possible terminal

location. There are many other harbor and offshore sites[5,6,7] suitable for deep draft tankers. It is logical to assume that an alternate northern terminal location would be selected if the area of interest for oil exploration were other than the National Petroleum Reserve.

The northern terminal must be capable of pumping the crude oil to the icebreaking tankers, processing dirty ballast, providing adequate housing and services for the terminal operating personnel, and providing protection and storage space for the cargo oil to afford it protection from the elements and to allow for unforeseen delays in tanker arrival and departure. A terminal design suitable for Smith Bay service is described in detail in reference 2. The proposed terminal has two parts. The cargo transfer station is located approximately 25 miles offshore in 100 feet of water and serves as a single point mooring with the capability of serving two ships simultaneously. It contains most of the facilities required for terminal operation. The land based station contains the facilities required for oil collecting, storing, and pumping. The terminal is sized to provide a 24-hour turnaround for an icebreaking tanker which carries two million barrels of crude oil. Should a northern terminal site other than Smith Bay be selected, an alternate terminal design may be necessary.

The topography of Smith Bay is typical of that of the entire North Slope region. It is not well suited for the development of an offshore terminal. The ocean floor has a very gentle slope until the water depth reaches approximately 500 feet where it then drops off drastically. Since the tower must be in approximately 100 feet of water to accommodate a tanker with a draft of 80 feet, the terminal platform

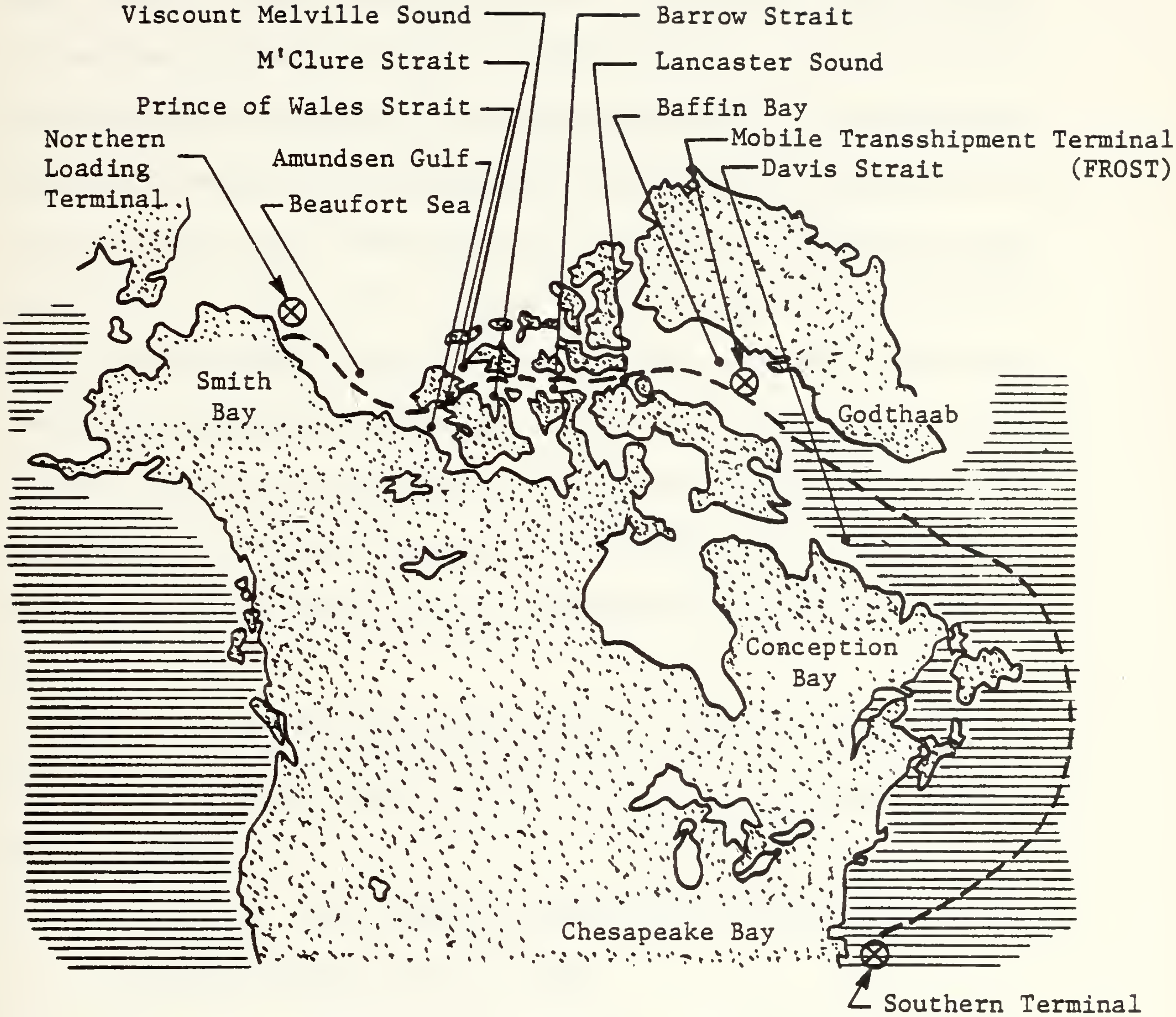
must be located approximately 25 miles offshore. This greatly increases the difficulty of laying the necessary pipeline from the shore station to the tower, and thus construction costs are increased. During the winter months the entire region is subjected to the attack of the polar ice pack and this will adversely affect both the construction and operation of the tower. Although many engineering and logistical problems are anticipated, construction and operation of the northern terminal is considered to be within today's "state of the art" technology[2,6].

Route

For the purpose of transporting oil from the Alaskan North Slope to the East Coast of the U.S. by ship, the following three routes are possible:

1. The western route through the Bering Strait
2. The polar route north of the Canadian Islands and Greenland
3. The Northwest Passage through the Canadian Islands (Figure 3-1).

The first alternative was rejected because of navigational hazards in the Bering Sea, extremely hazardous ice and weather conditions north and west of Alaska, difficulty in moving oil from the West to East Coast of the U.S., and duplication of effort with the Alaskan pipeline. The second alternative was rejected because of extremely severe ice and weather conditions in the Arctic Ocean. The third alternative was selected for this study. This route can accommodate a three-propellered icebreaking tanker capable of transporting approximately two million barrels of crude petroleum per trip[2].



Note: Wave pattern indicates approximate extent of year-round open water.

Figure 3-1[2]

Proposed Trade Route for Nuclear Powered Icebreaking Tanker Transportation System

Upon departure from the loading terminal, the icebreaking tanker will proceed across the Beaufort Sea keeping as far south as possible to avoid the most severe pressure ridges and ice conditions. The proposed route will then take the ship into the Viscount Melville Sound via Amundsen Gulf and the Prince of Wales Strait. From the Viscount Melville Sound the ship will proceed approximately in a straight line through the Barrow Strait, Lancaster Sound, and into Baffin Bay. Then the route turns south through the Davis Strait and ultimately to the East Coast of the U.S. The proposed route was navigated successfully by the USS SEA DRAGON during a submerged transit in 1960, and by the commercial icebreaker SS MANHATTAN in 1969 and 1970. Although Prince of Wales Strait is very narrow and will prevent two-way ship traffic, the remainder of the navigable waters are comfortably wide and deep. Therefore, the only major, though surmountable, obstacle will be the ice.

After the icebreaking tanker reaches the edge of the ice in the vicinity of the Baffin Bay-Davis Strait area, the following alternatives are possible:

1. Rendevous with a mobile terminal for transshipment as close as practicable to the ice edge
2. Continue southward to Godthaab, Greenland for transshipment
3. Continue southward to Conception Bay, Newfoundland for transshipment
4. Continue southward to the U.S. East Coast for transshipment or direct unloading to existing port facilities.

The first alternative was chosen for this study because it most effectively utilizes the unique features of the very expensive

icebreaking tankers. Their specialized design necessitates increased acquisition costs commensurate with their high horsepower ratings. Therefore, they will be unable to compete effectively in the open-water trades and must be fully utilized for Arctic operations. Although the other alternatives were rejected for this study, they are worthy of attention in subsequent economic analyses. Following cargo transshipment at the mobile terminal, conventional surface tankers will transport the crude oil to existing facilities on the U.S. East Coast.

Icebreaking Tankers

The key design information for these ships has been extracted from the data base in reference 2 for use in this economic analysis. This section describes the major features of the competing icebreaking tankers utilized in this study.

Nuclear Icebreaking Tankers

Except for two unusual features this ship is similar to any other large, modern tanker and uses "state of the art" design methods and components of proven technical adequacy. The two unusual features are:

1. Nuclear propulsion
2. Capability of operating through the Arctic winter.

Nuclear propulsion has not yet been applied to a large tanker in commercial service; however, the Consolidated Nuclear Steam Generator (CNSG) system proposed for this tanker is being developed for merchant services by the Babcock and Wilcox Company under the auspices of the Maritime Administration. The CNSG design is a much improved version

of the highly successful nuclear marine reactors used in the United States experimental ship, NS SAVANNAH, and the German cargo ship, NS OTTO HAHN. This reactor has been favorably reviewed by MarAd, the Nuclear Regulatory Commission, shipbuilders, and ship designers. A submittal to the N.R.C. for licensing will be required whenever a building contract is signed. Other regulatory requirements and constraints imposed by the United States and Canadian governments are detailed in reference 2.

Icebreaking in the Arctic winter is also a unique requirement. Massive thrust is necessary to drive a ship through a level sheet of fast ice on a continual basis, whereas inertia is required to keep the same vessel advancing through the harder and thicker multi-year ice ridges and hummocks. The 1969-1970 voyages of the fossil fueled SS MANHATTAN demonstrated the feasibility of such an operation, even though it was not economical for a ship of that size and power. The SS MANHATTAN, at 155,000 DWT and 43,000 SHP, possessed about the minimum amount of necessary mass, but far too little thrust[5].

One of the interesting characteristics of ice breaking is that there is no sharp demarkation between passable and impassable ice. As conditions become gradually more severe, the ship must proceed more and more slowly until it reaches a situation where it must back up, get a running start, and "ram" (sometimes repeatedly) to get through an obstruction. Sometimes it is better to go around an obstruction, even at the cost of many extra miles of travel. Unfortunately, there is no "standard equation" for predicting the speed of a new hull form through Arctic ice; sufficient data does not exist. The performance

data used in this study[2] are thought to be conservative, and it is expected that actual performance will be better than predicted.

Speed through ice depends on the ice thickness, strength, and pressure, and on the distribution of leads and pressure ridges. The icebreaking performance is rated at about 3.0 knots in average level ice 7.0 feet thick for a continuous mode with a 210,000 shaft horsepower (SHP) power plant. No anti-friction systems are provided. When conditions are more favorable, performance will obviously improve. When conditions are less favorable, the tanker will have the option of changing course to find an easier route or of backing and ramming to force its way through the obstructions. Either of these options will delay the voyage. Appropriate allowances for such delays are listed in Table 3-1.

Table 3-1[2]

Ice Related Delays that Should Be Incorporated
In the Voyage for the Arctic Icebreaking Tanker

	Average Ice Delays	Severe Ice Delays
August	0 hours	0 hours
September	0	0
October	2	8
November	2	8
December	4	16
January	6	24
February	8	32
March	12	48
April	12	48
May	12	48
June	4	16
July	0	0

The data in Table 3-1 represents an estimate of the ice related delays for a one-way voyage that may be anticipated for the icebreaking tanker during the passage from the Northern terminal to the mobile terminal or vice versa.

The power required to move through the ice is far in excess of that necessary for open water so the ship could operate at reduced power levels in the ice-free portions of its route. This study assumes, however, that the mobile terminal is positioned as close as practicable to the ice edge so open water performance will not be evaluated.

Ship size for this application is difficult to determine. The normal limitations on draft (harbor depth), length and beam (dry dock design), and height (bridge clearance) do not constrain the design. Increased displacement is advantageous, because it provides a larger cargo deadweight and would thus tend to reduce the Required Freight Rate. It also provides the momentum needed to break through ice pressure ridges with a minimum loss of speed. Conversely, increased displacement requires increased power for operating in level ice; and therefore, the maximum practical displacement is limited by the size of the propulsion plant. The displacements for the icebreakers analyzed in this study have been set at 333,290 and 313,290 DWT for the nuclear powered and fossil fueled ships, respectively, because these specifications are in close agreement with the Newport News Shipbuilding conceptual design[2] and with the specifications discussed in reference 8.

The nuclear icebreaking tanker will be powered by two 314 MWt Babcock and Wilcox CNSG systems each producing 120,000 SHP. Maximum

propulsion power will be approximately 210,000 SHP after allowances for hotel and miscellaneous loads. The main propulsion will be generated via three shafts through reversing reduction gears to fixed pitch propellers. Power per shaft is limited to approximately 70,000 SHP because of limitations on the size of propellers currently available commercially. It is important to note that a 210,000 SHP engine room is quite unique in the maritime industry and significant additional engineering effort will be required in support of this concept[9].

Double skin construction was selected for this vessel. A full double bottom is required by the USCG, because the ship has nuclear propulsion, and the double sides offer the following benefits for an Arctic tanker:

1. Efficient structural support of the ice-stiffened outer hull
2. Increased protection against oil spills caused by low-temperature steel ruptures after impact with heavy ice
3. Improved cleaning of cargo tanks
4. Reduced heat loss from cargo to seawater or air
5. Effective space utilization for clean ballast.

Two longitudinal bulkheads were selected over a single center line bulkhead to reduce the span of transverse girders. A center line pipe tunnel is provided in the double bottom to improve the cargo and ballast handling system.

The low temperature aspects of structural design for Arctic service were recognized during the Newport News Shipbuilding conceptual study and will require continued attention during ensuing design phases. Detailed design drawings are contained in reference 2.

Fossil Fueled Icebreaking Tankers

The fossil fueled ship was assumed to be very similar to the nuclear tanker with the exception of the main propulsion machinery. Only the differences will be summarized in this section.

The total deadweight of each vessel was assumed to be the same. Therefore, both the displacement and cargo capacity were affected because of differences in the lightship weight and fuel oil weight of the two ships. The lightship weight of the fossil fueled ship was found to be 20,000 tons less because of differences in the main power plants and omission of some collision protection structure. The fuel oil weight difference is significant because it reduces the amount of cargo that can be carried by the fossil fueled ship. The nuclear ship only carries reserve fuel oil for possible emergency diesel operation. This has been estimated at 831 tons[4]. The fossil fueled ship consumes an estimated 16,382 tons of Bunker C fuel oil per round trip and carries a 50% emergency fuel reserve or 8,191 tons. The fuel consumption for this ship was calculated in the following manner:

$$\frac{\text{LT}}{\text{Trip}} = 240{,}000 \text{ SHP} \times .9 \times \frac{.477\#}{\text{SHP-Hr.}} \times 14.84 \frac{\text{Days}}{\text{Trip}} \times \frac{1 \text{ LT}}{2240\#} \times \frac{24 \text{ Hr.}}{\text{Day}}$$

$$= 16{,}382 \frac{\text{LT}}{\text{Trip}} \qquad \text{where:}$$

$$.9 = \text{Plant Utilization Factor,}$$

$$\frac{.477\#}{\text{SHP-Hr.}} = \text{Fuel Consumption Rate.}$$

The power plant selected for this ship consists of a conventional boiler-steam turbine combination. Specifically, three 70,000 SHP

turbines will drive three fixed pitch propellers through reversing reduction gears.

The major characteristics of the two competing icebreakers are summarized in Table 3-2.

Table 3-2

Ship Characteristics

		Nuclear	Fossil
Length, Overall		1,283 ft.	1,260 ft.
Beam, Molded		150 ft.	150 ft.
Draft, Molded		80 ft.	80 ft.
Total Deadweight		249,851 LT	249,851 LT
Lightship		83,439 LT	63,439 LT
Displacement		333,290 LT	313,290 LT
Provisions		20 LT	20 LT
Fresh Water		150 LT	150 LT
Constant DWT		500 LT	500 LT
Fuel Oil:	Reserve (Emerg)	831 LT	8,191 LT
	Consumed	0	16,382 LT
Cargo		248,350 LT	224,608 LT

This section has detailed the basic characteristics of the icebreaking tankers. Supplemental information is provided in Chapter V during the development of the reference case economic analysis.

It should be reemphasized that this study has not attempted to optimize the icebreaking tanker design. In fact, the very detailed analysis, albeit not an economic one, in reference 2, concluded that

a nuclear power plant supplemented with a combined steam and gas turbine plant for "boost" power requirements was the best alternative. During the course of this research, however, discussions with experts in this field, specifically representatives from the Maritime Administration, Newport News Shipbuilding, Babcock and Wilcox, ARCTEC, Inc., Mobil Shipping and Transportation Co., the Energy Research and Development Administration, and the NUS Corporation, have indicated that an economic comparison between an all-nuclear and an all-fossil plant was of significance to the industry.

Mobile Terminal

The mobile transshipment terminal concept permits cargo transfer at the edge of the ice pack. This study makes use of the FROST (Floating Repair and Oil Storage Terminal) conceptual design previously conceived by Newport News Shipbuilding for similar service[10]. The original FROST design cost was updated and modifications were made to provide oil storage capacity of six million barrels and to add four thrusters for maneuvering, station keeping, and ship control during transshipment operations[11]. Estimated construction and operating costs for the FROST are examined in Chapter V.

Conventional Tankers and Southern Terminal

The estimation of capital and operating costs of appropriate surface tankers and unloading terminals utilized current RFR's and port charges as experienced by oil companies for surface tankers to account for the costs of the final leg of the journey. This data was provided

by Newport News Shipbuilding and the Mobil Shipping and Transportation Company. The contribution of this cost component to the total system RFR is evaluated in Chapter V, Economic Analysis: Reference Case.

IV. ECONOMIC CRITERIA

General

The economic measure of merit or criterion utilized in this study is the Required Freight Rate (RFR). This criterion, which is widely used for bulk cargo carriers when revenues are unknown, implies that the best ship is the one offering a specified service at the lowest unit cost to the customer while returning to the owner a reasonable level of profitability after taxes[3]. The definition for RFR is:

$$\text{RFR} = \frac{\text{Average Annual Cost}}{\text{Average Annual Cargo Units Carried}}$$

where the average annual cost is equal to the sum of the annual capital recovery cost, the annual operating cost, the annual voyage cost, and the annual fuel cost. Each of these cost categories, as well as the annual cargo carried, is discussed later. The RFR is not intended to be used as an indication of the freight rate which should be charged by any particular owner. Actual freight rates are established by free competition in the marketplace and will fluctuate with supply and demand. The RFR only provides a measure of the desirability to any prospective owner of investing in the ship or system under consideration, instead of in some other investment which would produce the specified interest or equity return[4].

The economic analyses performed during this study have been done using a discounted cash flow technique. This principle is based on the concept that, on any specified date, payments to be made in the future are less valuable than payments already made because of the interest

that money-in-hand earns, and money-not-yet-received does not earn. The present value of any payment depends on the following:[4]

1. The amount of the payment
2. The time between the "present value date" and the payment date. Payments become less valuable as they progress further into the future and are more valuable if they occur before the "present value date."
3. The interest (or equity return) rate which money would earn if it were available for investment.

Any date can be chosen as the "present value date" without affecting the validity of the study results. For this paper the assumed delivery date, 1 January 1984, has been selected as the "present value date."

A major problem which must be confronted during an economic evaluation such as this is how to deal with cost escalation. The escalation of capital and operating costs is difficult to assess for the following reasons:

1. If cost escalation is accounted for in the analysis, the subject escalation factors are, at best, "educated guesses."
2. If cost escalation is ignored, a capital intensive cost component, e.g., a nuclear icebreaking tanker, is not properly perceived financially.

There are two major approaches to the problem of analyzing the effects of operating cost escalation on the economics of system operation, and they lead to significantly different results. The two approaches are as follows:

1. Ignore escalation completely

2. Utilize a uniform escalation rate for the life of the system components where the component escalation rates may be different for different costs but remain constant with time.

In the latter approach an "average" value of RFR is determined which produces more income than is needed to meet the low costs in the early part of the system life, and less than is needed for the later high costs. Excess early income is theoretically used to establish a "sinking fund" to meet the later deficits. It is obvious that the choice of analysis approach will affect the dollar value of RFR. Perhaps it is not as obvious, however, that it will also affect any comparison of the RFR of one system configuration with that of another. This is because the combination of "present value" calculations and escalation factors have different effects on capital costs and operating costs. Systems with a high acquisition cost/operating cost ratio may appear better than ships with a low ratio if operating costs are escalated, but appear worse than those same systems if operating costs do not escalate[4]. Both of these latter approaches have been used during the course of this study. The reference case has included the effects of capital and operating cost escalation.

The role of the government under the auspices of the Maritime Administration in the nuclear merchant ship program is not fully defined; therefore, various levels of government participation were investigated in Chapter VI, Economic Analysis: Sensitivity Studies. The reference case assumed very minimal government participation in keeping with a conservative approach.

Two computer programs, attached to this study as Appendices A and B, were written to facilitate the RFR computation for the transportation systems utilizing a nuclear powered icebreaking tanker and fossil fueled icebreaking tanker, respectively. The remainder of this chapter discusses the methodology utilized in formulating the computer programs.

Total Average Annual Cost

The average annual cost (AAC) required to operate the transportation system includes average annual capital recovery costs, average annual operating costs, and the average annual fuel costs. Capital recovery costs include costs associated with acquisition of the ships and the terminals. Included in the annual operating costs are: icebreaker tanker operating costs and the northern and mobile terminal operating costs. The average annual cost is then:[12]

$$\text{AAC} = (\text{CAOC})\text{CRF}(X,\text{SL}) + (\text{STCC} + \text{SIMIS})\text{CRFT}(X,\text{DT}) + (\text{TERMC})\text{CRFTT}(X,\text{DTT}) \quad \text{where:}$$

AAC = Average Annual Cost

CAOC = Cumulative present worth of the annual operating costs at delivery date

CRF(X,SL) = Capital recovery factor, excluding taxes, at rate X for SL years.

STCC = Cumulative present worth of icebreaking tanker construction cost at delivery date

SIMIS = Tanker predelivery costs at delivery date

CRFT(X,DT)	=	Capital recovery factor, including taxes, at rate X for DT years
TERMC	=	Cumulative present worth of terminal acquisition cost at delivery date on a per ship basis (includes both the northern and mobile terminals).
CRFTT(X,DTT)	=	Capital recovery factor, including taxes, at rate X for DTT years
X	=	Effective cost of money
SL	=	Ship life, years
DT	=	Ship depreciation time, years
DTT	=	Terminal depreciation time, years

Average Annual Operating Cost

Each cost category contributing to the average annual operating cost (AAOC) is investigated quantitatively in the following chapter. However, the basic computational approach is outlined here:

AAOC	=	(CAOC)CRF(X,SL)
CAOC	=	PVFC + STOC where:
PVFC	=	Cumulative present worth at delivery date of the fuel costs over the life of the ship
STOC	=	Cumulative present worth at delivery date of the ship and terminal operating costs over the life of the ship
PVFC	=	[AFC(I)]PWF(X,I)

$$STOC = [TAOC(I)]PWF(X,I) \quad \text{where:}$$

$AFC(I)$ = Annual fuel cost for year I

$TAOC(I)$ = Ship and terminal operating costs for year I

$PWF(X,I)$ = Present worth factor at rate X for I years.

The present value of total annual operating costs and fuel costs over the life of the ship was determined by escalating the individual cost factors each year, and then using the effective cost of money (described below) to determine the cumulative present worth of these annual costs. Then the CAOC was spread out over the life of the ship using the before tax capital recovery factor to yield a uniform annual operating cost over the life of the ship.

Capital Costs

The cost of capital for this system consists of the costs associated with the icebreaking tanker and the northern and mobile terminal acquisitions. A detailed cost breakdown is analyzed in the following chapter, however, the basic methodology is outlined below. The average annual capital cost is then:

$$AACC = (STCC+SIMIS)CRFT(X,DT) + (TERMC)CRFTT(X,DTT)$$

The value of STCC was obtained by summing the present worth at delivery date of all the individual cost payments over the tanker construction period. Specifically:

$$STCC = \sum_t ICC(t)CAF(x,t) \quad \text{where}$$

$CAF(x,t)$ = Compound amount factor at rate x for time t

ICC(t) = Individual construction cost payment at time t (progress payments)

By defining all time prior to the delivery date as negative,

$$STCC = \sum_{t} ICC(t)PWF(x,t)$$

where t is negative. Escalation of construction costs during the construction period was accounted for in the model. The value of TERMC was determined using the techniques described above for STCC. Pre-delivery costs, e.g., SIMIS, were input directly into the computer program as described in the following chapter.

After the cumulative present worths of the ship and terminal construction were calculated, their respective costs were spread out over the life of the system using the after-tax capital recovery factor to yield a uniform annual capital recovery cost over the life of the system.

Capital Recovery Factor

The capital recovery factor, CRF(x,t), is a value which when multiplied by the present worth of some quantity, e.g., mortgage, value of a ship, terminal, etc., will yield the average annual return required, at rate x for t years, to liquidate the commitment. The CRF(x,t) used assumed no salvage value (discussed later) and did not include income taxes. The equation for CRF(x,t) is as follows[13]:

$$CRF(x,t) = \frac{A'}{P} = \frac{x}{1-(1+x)^{-t}}$$

where P = Present worth of mortgage, ship, terminal, etc.

A' = Average annual return required after taxes.

The CRF(x,t) must be modified to account for the added cost of income taxes so that the resulting average annual return is large enough to include all of the costs included in A' plus income taxes. Assuming straight line depreciation for tax purposes (an economically conservative assumption), the depreciation equals P/N where N equals the ship or terminal lifetime in years. Annual taxes equal the tax rate times the annual return before taxes less depreciation. The relationship between returns before and after taxes, as shown in Figure 4-1[14] is:

$$A' = A - r\,(A-P/N) \qquad \text{where}$$

A = Average annual return required before taxes

r = Effective income tax rate

or $$A' = A - rA + \frac{rP}{N}$$

so $$A' = A(1-r) + \frac{rP}{N}$$

$$\frac{A'}{P} = \frac{A}{P}(1-r) + \frac{r}{N}$$

But since

$$\frac{A'}{P} = \text{CRF and } \frac{A}{P} = \text{CRFT}$$

we have $$\text{CRF} = \text{CRFT}(1-r) + \frac{r}{N}$$

or the modified capital recovery factor (after taxes) is:

$$\text{CRFT} = \frac{\text{CRF} - \frac{r}{N}}{1-r}$$

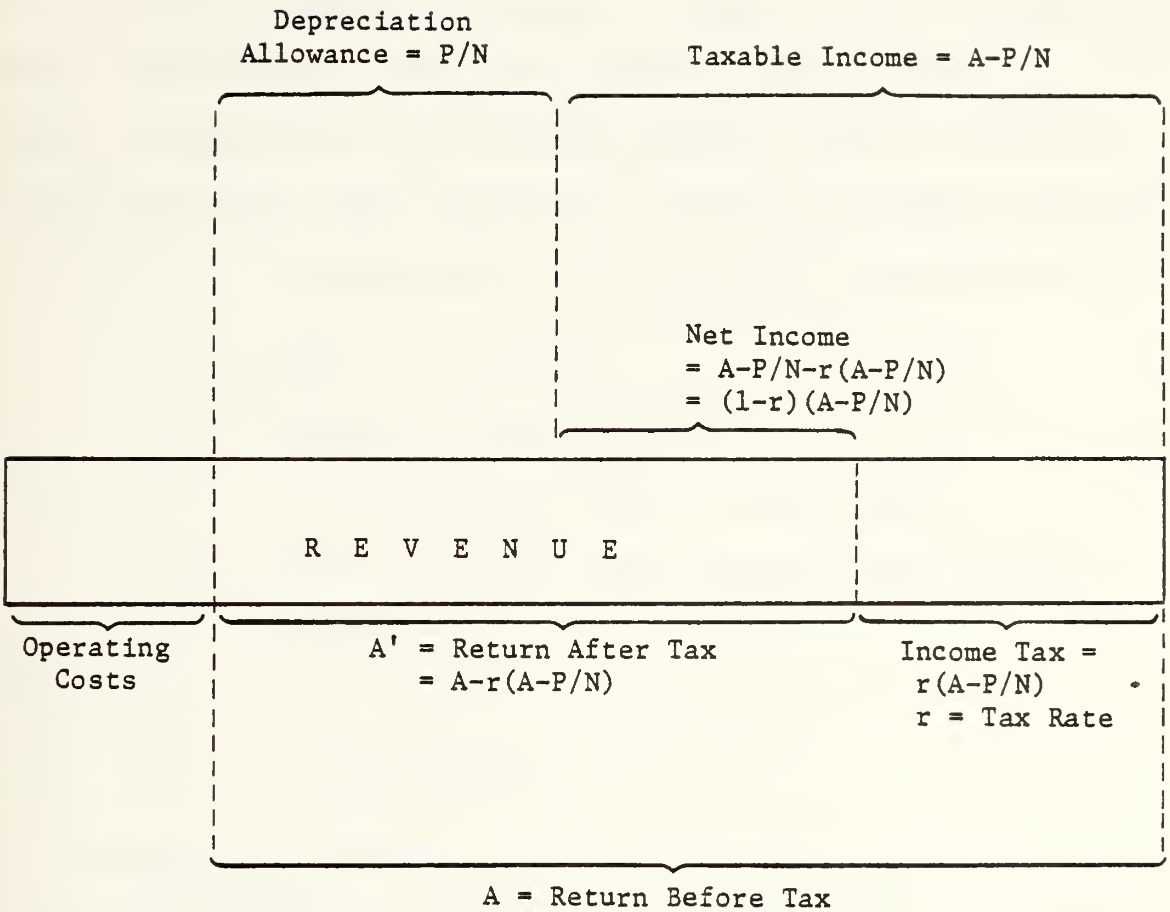


Figure 4-1[14]

Division of Revenue
(All amounts on an annual basis)

Cost of Money

To obtain the effective cost of money, x, the capitalization structure of a company must be considered. Capital can be raised through borrowing from a lending institution or through the sale of bonds and/or stocks. The bank loan and/or bonds require a certain interest rate of return. A prerequisite for the sale of stock is that the company has a sufficiently high equity return rate to make the investment attractive to the public. The direct cost of money can then be represented as:[15]

a = Direct cost of money

BI = The bank or bond interest rate

B = The debt-to-capital ratio for the company

ER = Equity return rate after corporate taxes have been deducted.

Then,

$$a = (BI)(B) + ER(1-B)$$

The effective cost of money is then the direct cost of money less the savings in income tax due to the deductible nature of the interest on the bank loans and/or bonds:[16]

$$x = (BI)(B) + ER(1-B) - (BI)(B)(r)$$

r = Effective income tax rate.

The value of r is derived for a Pennsylvania corporation (1971) as follows:[17]

FIT = Federal income tax

SIT = State income tax

TIF = Taxable income - federal

$$TIS = \text{Taxable income - state}$$

$$NOLD = \text{Net operating loss deduction}$$

$$FIT = .48\ (TIF\text{-}NOLD) - \$6{,}500.00$$

$$SIT = .12\ (TIS)$$

$$TIS = TIF + SIT$$

$$SIT = .12\ (TIF+SIT) = .136364\ (TIF)$$

$$\text{Total Income Tax} = FIT + SIT$$

$$= .616364\ (TIF) - .48\ NOLD - \$6{,}500.00$$

If the company suffers no net operating loss, and if the TIF is large in comparison to the $6,500, the effective income tax rate can be simplified to: $r = .616364$.

Average Annual Cargo Units Carried

The average annual cargo units carried, and in this study, the number of barrels of crude oil transported from the North Slope to the East Coast annually, is a function of at-sea time, number of days per voyage, and the number of barrels carried per voyage. Each of these input parameters will be dealt with in the following chapter.

Summary

The economic model and analysis methodology described qualitatively in this chapter provides a means of making an accurate evaluation of the economic viability of the transportation system and a valid comparison between the alternative icebreaking tankers under discussion. The economic model and computer programs used in this study were verified using a similar model and computer program contained in reference 4.

That is, the economic problem evaluated in reference 4 was analyzed using the economic model and computer programs developed for this study. The results obtained in reference 4 and the results obtained using the economic model and computer programs contained herein agreed within an accuracy of five percent.

V. ECONOMIC ANALYSIS: REFERENCE CASE

Each element contributing to the Required Freight Rate is quantitatively analyzed in this section. Some of the data used in this analysis was developed during the course of this study, some was generated in previous studies[4,5,11,18,19] and some, particularly the various escalation factors, represent "best estimates" of the proper value.

The following assumptions apply to this reference case analysis:

1. Construction costs are expressed in 1978 dollars and escalated during the construction period to the time of each progress payment.
2. Operating costs are expressed in 1984 dollars and escalated during the system lifetime.
3. Construction and operating differential subsidies are not considered.
4. A Nuclear Incentive Allowance is not considered, i.e., CNSG costs are not subsidized by the government.
5. Cost savings inherent in multiship construction are not considered.

Table 5-1 lists the basic economic data used for this reference case. The effective income tax rate is applicable only for Pennsylvania corporations. The other values are typical industry values.

Table 5-1

Reference Case Economic Data

After Tax Equity Return Rate	=	.12
Bank or Bond Interest Rate	=	.09
Debt to Total Capital Ratio	=	.75
Effective Income Tax Rate	=	.616364

Prior to evaluating each element required for the RFR calculation, it is necessary to describe the operating schedule and fleet requirements for this transportation system.

Voyage Length

The average round trip distance from the northern loading terminal at Smith Bay, Alaska to the mobile transshipment terminal (FROST), is 3900 nautical miles. Table 5-2 lists the estimated times for round trip voyages from Smith Bay to the FROST for each month of the year. The table is based on a 24-hour turnaround time at each terminal and on the average ice delays listed in Table 3-1. Average ice conditions were calculated by ARCTEC, Inc. and are described in reference 2.

Table 5-2 indicates that each ship can make 21.68 trips per year. However, the ship cannot operate 365 days per year because of necessary voyage repairs, refueling (nuclear), and overhaul. On the average, each round trip requires 16.84 days; two days turnaround, and 14.84 sea days.

Table 5-2

Voyage Times
Smith Bay to FROST

Month	Days/Round Trip		Trips/Month
January	18.6		1.67
February	23.6		1.19
March	30.1		1.03
April	48.1		.62
May	54.1		.57
June	21.1		1.42
July	12.1		2.56
August	10.6		2.92
September	10.6		2.83
October	11.6		2.67
November	13.6		2.21
December	15.6		1.99
		Total	21.68 Trips/Year

Tanker Availability

This study assumes the following number of days per year for icebreaking tanker availability:

Fossil fueled tanker system 332.92 days

Nuclear powered tanker system 325.72 days.

Tables 5-3 and 5-4 show the number of days each year the icebreaker tanker will be available for the fossil and nuclear systems, respectively. The two competing tankers are assumed to be out of service for routine voyage repairs an identical amount of time, and each is scheduled to go into a U.S. shipyard every year. However,

Table 5-3

Ship Availability
Fossil Fueled Icebreaking Tanker

Year	Days Voyage Repairs	Net Travel Days	Days Shipyard Repairs	Add'l. Days Major Repairs	Gas Freeing	Total Days Repairs	Oper. Days/ Year
1	5	5	12		5	27	338
2	5	5	12		5	27	338
3	5	5	12		5	27	338
4	5	5	12		5	27	339
5	5	5	12		5	27	338
6	5	5	12		5	27	338
7	5	5	12		5	27	338
8	5	5	12		5	27	339
9	5	5	12		5	27	338
10	5	5	12		5	27	338
11	5	5	12		5	27	338
12	5	5	12	60	5	87	279
13	5	5	12		5	27	238
14	5	5	12		5	27	238
15	5	5	12		5	27	238
16	5	5	12	60	5	87	279
17	5	5	12		5	27	238
18	5	5	12		5	27	238
19	5	5	12		5	27	238
20	5	5	12	30	5	57	309
21	5	5	12		5	27	338
22	5	5	12		5	27	338
23	5	5	12		5	27	338
24	5	5	12		5	27	339
25	5	5	--		-	10	355
Totals	125	125	288	150	120	808	8323

Average Ship Availability (25 years) = 332.92

Table 5-4

Ship Availability
Nuclear Powered Icebreaking Tanker

Year	Days Voyage Repairs	Net Travel Days	Days Shipyard Repairs	Add'l. Days Major Repairs	Gas Freeing	Total Days Repairs	Oper. Days/ Year
1	5	5	12		5	27	338
2	5	5	32		5	47	318
3	5	5	12		5	27	338
4	5	5	32		5	47	319
5	5	5	12		5	27	338
6	5	5	32		5	47	318
7	5	5	12		5	27	338
8	5	5	32		5	47	319
9	5	5	12		5	27	338
10	5	5	32		5	47	318
11	5	5	12		5	27	338
12	5	5	32	40	5	87	279
13	5	5	12		5	27	338
14	5	5	32		5	47	318
15	5	5	12		5	27	338
16	5	5	32	40	5	87	279
17	5	5	12		5	27	338
18	5	5	32		5	47	318
19	5	5	12		5	27	338
20	5	5	32	10	5	57	309
21	5	5	12		5	27	338
22	5	5	32		5	47	318
23	5	5	12		5	27	338
24	5	5	32		5	47	319
25	5	5	--		-	10	355
Totals	125	125	528	90	120	988	8143

Average Ship Availability (25 years) = 325.72

every other year the nuclear powered tanker is out of service longer to accommodate a 32-day refueling schedule. During the twelfth, sixteenth, and twentieth years, additional days are allowed for major repairs as the ships get older[11]. During the twelfth and sixteenth years each ship undergoes a 72-day shipyard overhaul. During the twentieth year each ship undergoes a 42-day shipyard overhaul. For this transshipment system, travel time from the FROST to U.S. shipyards for repair and overhaul will require five days one way. Gas freeing, normally a five-day shipyard evolution for tankers of this size, will take place while enroute to the shipyard. Therefore, only five days' travel time are added for the trip back into service after shipyard repair[11]. Table 5-5 summarizes the voyage data for the competing transportation systems.

Table 5-5

Voyage Data

	Fossil	Nuclear
Route Distance (one-way) n.m.	1950	1950
Round Trip Time (Days):		
Sea Time	14.84	14.84
Turnaround	2.0	2.0
Total Days	16.84	16.84
Ship Availability Days/Year	332.92	325.72
No. of Trips/Yr./Ship	19.8	19.3
Sea Days/Year	303.4	297.0
Cargo Capacity (10^6 bbl/trip)	1.654	1.829
Design Sys. Thruput/Yr. (10^6 bbl/yr)	730.5	730.5
No. of Icebreakers Required	23	21

It should be noted from Table 5-5 that *the fossil fueled tanker transportation system would require two additional icebreaking tankers for design, steady state operation. This difference in fleet requirements was not factored into the computer economic analysis quantitatively and the Required Freight Rate was calculated on a per ship basis assuming a fleet of 21 icebreaking tankers for each system.* This is discussed more fully later.

The <u>average</u> performance figures detailed in Tables 5-2 through 5-5 were used for the economic analyses in this study. This approach simplifies the economic model yet yields creditable results.

The following points should be noted, however:

1. Scheduling of these ships presents a problem because of the large differences in round trip voyage times between the summer and winter months. During optimal weather conditions two ships per day would arrive at each terminal; whereas, severe weather conditions in the Arctic winter would reduce the arrival rate to one tanker every two or three days. The system must, therefore, have sufficient terminal pumping and storage capacity to accommodate these fluctuations in arrival frequency.
2. The cargo carrying capacity of the fossil fueled tanker would be severely curtailed during the rough winter months because the fuel consumption per round trip voyage would be prohibitive.

The remainder of this chapter is devoted to analyzing the specific elements which comprise the various inputs to the Required Freight Rate

calculation. The cost elements are depicted schematically in the flow diagram shown on Figure 5-1. The cost elements shown on Figure 5-1 will be addressed in the following order:

1. Acquisition Cost - This includes the icebreaking tanker construction and predelivery capital costs and the northern and mobile terminal construction and predelivery capital costs.
2. Operating Cost - This includes the icebreaking tanker average annual operating costs and the northern and mobile terminal average annual operating costs.
3. Fuel Cost - This includes the average annual cost of Bunker C fuel oil and nuclear fuel for the fossil fueled and nuclear powered icebreaking tankers, respectively.
4. Average Annual Cargo Units Carried
5. Conventional RFR Calculation - This includes the determination of the surface tanker RFR from the mobile transshipment terminal to the Delaware River Terminal. This value is designated CONRFR in the computer programs and on Figure 5-1. CONRFR is then added to the RFR calculated for the voyage from the northern terminal to the mobile transshipment terminal (SUBRFR) to yield the system RFR (TRFR).

Tanker Construction Cost

Construction costs for purposes of this study are divided into the following categories:

1. Hull Steel and Outfit/Auxiliary Systems - This includes the hull structure and superstructure with all internal divisional

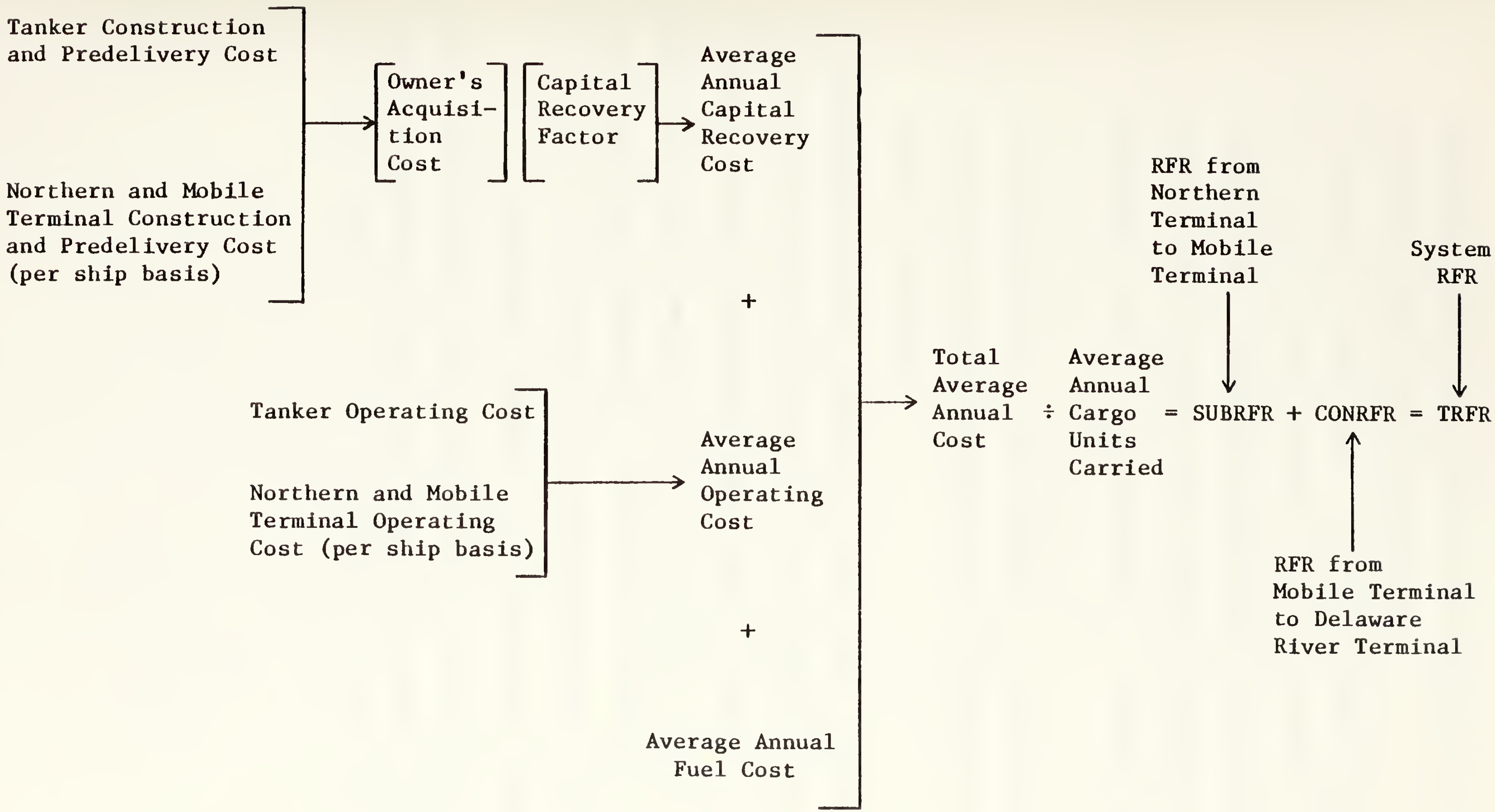


Figure 5-1[20]

Required Freight Rate Calculation Procedure

bulkheads and all ship systems with the exception of the propulsion plant and its auxiliaries.

2. Power Plant - This includes the entire propulsion system from the boilers to the prcpellers including associated auxiliary systems. For the nuclear powered tanker this includes the pumps, control systems, other auxiliary equipment, secondary shielding, and the collision barrier. It does not include the cost of the two CNSG units.
3. Consolidated Nuclear Steam Generator - This includes the cost of the two 120,000 SHP CNSG units, excluding the fuel, delivered to the shipyard.

No salvage value was assumed for either ship. The salvage value of the nuclear tanker would exceed that of the fossil tanker by about $5.5 million when the first ships were ready to retire from the fleet[18]. However, the nuclear tanker would incur additional decommissioning costs of the same order of magnitude. Therefore, no advantage or disadvantage was assigned to either ship type for these end-of-life values.

Table 5-6 summarizes the ship construction costs utilized in this study. These budgetary cost estimates were verified verbally by industry personnel from the Babcock and Wilcox Company and Newport News Shipbuilding referred to in the acknowledgment of this paper.

Table 5-6

Icebreaking Tanker Construction Cost

	Fossil	Nuclear
Hull Steel and Outfit/ Auxiliary Systems	$245,000,000	$245,000,000
Power Plant	30,000,000	90,000,000
CNSG (2)		110,000,000
Total	$275,000,000	$445,000,000

Progress Payments

The shipbuilders and power plant vendors receive progress payments based on the percentage of completion. The shipowner retains 10% of the cost as a guarantee against meeting specifications until the guarantee period, assumed to be one year for the ship and two years for the power plant, is over. The predelivery payments will be based on a straight line approximation with payments at six-month intervals. These payments will be brought forward to the ship delivery date using the present worth techniques described in Chapter IV, Economic Criteria[15]. Contracts for ships of this size include an escalation clause. The base prices are expressed in January 1978 dollars and escalation to the date of each payment is 8% per year. The construction cost is then amortized over a 25-year period. The progress payments for the nuclear ship are distributed over the final 63 months of the building period in accordance with the assumed pattern of cash flow. Progress

payments for the fossil fueled ship are distributed in a similar manner over the final 48 months of the building period, because the actual construction will take this shorter time[4]. The progress payments for the CNSG will also be distributed over a 48-month period.

Tables 5-7 and 5-8 show the simplified progress payment schedules.

Table 5-7

Prepayment Schedule
Fossil Fueled Tanker

Ship		Power Plant	
Years Before Ship Delivery	% of Total Cost	Years Before Plant Delivery	% of Total Cost
-3.5	11.25	-3.5	11.25
-3.0	11.25	-3.0	11.25
-2.5	11.25	-2.5	11.25
-2.0	11.25	-2.0	11.25
-1.5	11.25	-1.5	11.25
-1.0	11.25	-1.0	11.25
-0.5	11.25	-0.5	11.25
0.0	11.25	0.0	11.25
+1.0	10.0	+2.0	10.0

Table 5-8

Prepayment Schedule
Nuclear Powered Tanker

Ship		Power Plant	
Years Before Ship Delivery	% of Total Cost	Years Before Plant Delivery	% of Total Cost
-5.25	7.5	-3.5	11.25
-4.75	7.5	-3.0	11.25
-4.25	7.5	-2.5	11.25
-3.75	7.5	-2.0	11.25
-3.25	7.5	-1.5	11.25
-2.75	7.5	-1.0	11.25
-2.25	7.5	-0.5	11.25
-1.75	7.5	0.0	11.25
-1.25	7.5	+2.0	10.0
-0.75	7.5		
-0.25	7.5		
0.0	7.5		
+1.0	10.0		

Ship Predelivery Costs

Predelivery costs for the nuclear ship fall into the following categories: initial crew training, initial baseline inspection of the reactor plant, and initial miscellaneous expenses such as the application fee for a construction permit, the construction permit fee, operating license fee, and construction administration expenses. The only predelivery expense attributed to the fossil fueled ship is the cost of construction administration.

Initial Crew Training - This expense refers to those costs incurred by the shipowner (prior to ship delivery) for the schooling of original crew members. This training is currently provided by the Merchant Marine Academy and others for the crews of fossil fueled ships. It is assumed that this same training will eventually be available for nuclear crew members. However, it has been treated as a nuclear ship pre-delivery cost in this study. The average training time for a crew of 38 men is assumed to be six months over and above that required for the fossil fueled tanker crew members. If a longer training period should be required, its effect on the overall system economics would be minimal. It is further assumed that the instructors' wages and non-recurring or fixed costs for a training and simulation building, course materials, training aids, etc. will be defrayed by Mar Ad for the first several years of system operation. The initial crew training cost is then:

$36,300/man/training period x 38 men = $1,379,400/training period.

Initial Baseline Inspection - This expense refers to the costs associated with conducting a detailed inspection of the pressure boundary of the reactor coolant system. The estimated cost is approximately $653,000 including labor, software, and hardware.

Construction Administration - This cost is assumed to be 20% greater for the nuclear ship because of the nuclear complexity. The construction administration cost is estimated to be $6523/month and $7828/month for the fossil and nuclear ships, respectively.

Application Fee for Construction Permit - This cost is estimated to be $128,500.

Construction Permit Fee - This cost is estimated to be $169,000.

Operating License Fee - This cost is estimated to be $275,000.

Table 5-9 summarizes the predelivery costs for the two ships.

Table 5-9

Predelivery Costs - Icebreaking Tankers

	Fossil	Nuclear
Construction Administration	$411,426	$ 689,094
Initial Crew Training		1,379,400
Initial Baseline Inspection		653,000
Application for Construction Permit		128,500
Construction Permit Fee		169,000
Operating License Fee		275,000
Total	$411,426	$3,293,994

Terminal Construction Costs

The cost estimates in this section should be regarded with caution since they are based solely on design concepts and not on past operating experience. Furthermore, the conceptual design work has been constrained by such factors as the following:

1. No field work has been done.
2. Information on site physical conditions is limited.

3. The construction season in the Arctic, particularly offshore, is uncertain as to time and length.

Northern Loading Terminal

The terminal construction cost is estimated at $1284 million. Table 5-10 details the various construction cost components.

Table 5-10

Construction Cost
Smith Bay Loading Terminal

Description of Facility		Cost (1978 $ Millions)
Tankage		137.0
Loading/Unloading		60.0
Ballast Treatment		38.0
Off-Shore Tower		415.0
Undersea Pipeline		313.0
Utilities		146.0
Buildings and General Plant		36.0
Sea and Air Transportation		5.0
Helicopter, Tugs, Small Craft		17.0
Contingency Allowance (10%)		117.0
	Total	1284.0

This cost estimate does not include an allowance for covering the pipelines and other transmission lines offshore. It is not known at this time whether this will be necessary because sufficient data is

not available as to depth, frequency, or probability of experiencing ice scoring. Progress payments and cost escalations were treated as in the case of the nuclear icebreaking tanker.

Mobile Transshipment Terminal (FROST)

The mobile transshipment terminal permits cargo transshipment at the edge of the ice pack. This vessel is designed to provide all normal logistic support to the tanker fleet, including some docking and voyage repairs when required. It is intended to be essentially self-supporting for the life of the system. The construction cost for the FROST is estimated at $321 million.

Terminal Predelivery Costs

Initial crew training and terminal administration costs incurred by the operator during the construction period are treated as pre-delivery capital costs. The terminal administration costs incurred by the operator during the construction period are estimated at 1/4% of the terminal construction costs for both the northern terminal and the FROST.

The initial crew training for the Smith Bay terminal is estimated at $1.46 million. With an average four-month training period for the 57-man crew, the personnel training cost amounts to $525,000. The instructors' salaries are estimated to total $75,000. The estimate of non-recurring charges for course preparation, materials, documentation, etc. is $860,000.

The initial crew training cost for the FROST is estimated at $2.69 million. These costs consist of wages paid during training for

two 91-man crews ($1,680,000), instructors' wages ($150,000) and non-recurring costs ($860,000).

Table 5-11 summarizes the total capital costs for the Smith Bay terminal and the FROST. These capital costs are amortized over a 35-year period; the assumed operational lifetime of the two terminals. Should this assumed lifetime be somewhat in error, both the nuclear and fossil systems would be affected economically. The comparison between the two systems, however, should remain virtually unaffected. The following chapter, Economic Analyses: Sensitivity Studies, investigates the effects of widely varying terminal construction costs on the system RFR's.

Table 5-11

Total Capital Costs
For Arctic Terminals

	Smith Bay ($1978 Millions)	FROST
Terminal Construction Cost	1284.000 (Table 5-10)	321.000
Initial Crew Training	1.460	2.690
Terminal Administration	3.210	.803
Total Capital Cost	1288.670	324.493
Total Capital Cost per Ship	61.365	15.452

To keep the ships at sea and the terminals operating, the prospective owner has a number of expenses in addition to amortization payments and fuel costs. These operating expenses are discussed below and summarized later in Tables 5-12 and 5-13.

Tanker Operating Costs

These costs fall into the following categories: crew cost, stores and supplies cost, maintenance and repair cost, insurance cost, miscellaneous cost, extra shore staff cost (nuclear), inspection cost (nuclear), refueling cost (nuclear), and attrition training cost (nuclear).

Crew Cost

Accommodations will be provided for an operating complement of 38 persons and for six other persons (riders). The nuclear crew will consist of 21 officer/engineering, six steward, and 11 deck department personnel. The annual salary including wages and fringe benefits, averaged over the entire crew, is estimated at $74,000 in 1984 dollars. The subsistence allowance is estimated at $8.00 per man per day. The annual crew cost for the nuclear powered tanker is then $2,911,019. The Office of Maritime Manpower has published data showing that crew wages have risen an average of 6% per year since 1949[15]. Therefore, a 6% per year escalation rate for this cost is assumed for the life of the ship.

The complement for the fossil fueled icebreaking tanker is decreased by ten persons in the engineering department because of less stringent watchstanding requirements and no requirement for a health physicist/water chemist. The annual crew cost for the fossil fueled tanker is then $2,146,574. This cost is also escalated at 6% per year.

This study has assumed that the annual salaries, including wages and fringe benefits, are the same for the nuclear and fossil icebreaking

tanker crews. It is possible that the average wage for the nuclear crew member may be higher. If this should occur, the effect on the economic comparison would be minimal and has been neglected in this study.

Stores, Supplies and Equipment Cost

This item includes the cost of all consumable stores, supplies, and equipment used in maintaining the hull and machinery. This cost is estimated to be $600,000 annually for each ship. This item is escalated at 8% per year to account for the increasing cost of material.

Maintenance and Repair Cost

Those expenses incurred which are not covered by insurance are included in this cost item. This cost is estimated at $1,950,000 in 1984, delivery date, dollars for the nuclear ship and is escalated at 8% per year for the life of the ship. Nuclear ship costs are higher because of the greater complexity of the double CNSG installation. Therefore, maintenance and repair costs for the fossil fueled tanker are estimated to be only 75% of the nuclear cost, or $1,465,000.

Insurance Costs

Protection and Indemnity - This insurance protects the company against lawsuits involving the crew, third party, fixed objects, and cargo. This coverage includes:

Crew - Protects against liability as the result of injury or death of an employee.

Third Party - Protects against liability as the result of injury to persons other than employees who board the ship. This includes longshoremen, maintenance men, etc.

Fixed Objects - Protects against damage to piers, navigation aids, and other fixed objects.

Cargo - Protects against liabilities relative to damage or loss of cargo.

The cost of this insurance is related to deadweight tonnage and is assumed to be $1.25 per deadweight ton. The annual cost for both ships is $312,314. This cost does not escalate.

Hull and Machinery - This insurance protects the company from damage or loss of the vessel and is proportional to the value of the ship. This cost is assumed to be 1.125% of the gross price of each vessel and does not escalate, because the decrease in ship value tends to offset the increase in material and labor cost for repairs. The annual costs are $5,006,250 and $3,093,750 for the nuclear powered and fossil fueled tankers, respectively.

War Risk - These insurance premiums are no longer required so this cost is zero for both ships.

Third Party Nuclear Liability - This insurance is required to protect the company in the event of an accident that results in the release of radioactive materials that cause death or injury to third parties. This item is assumed to cost $1,150,000 and the cost does not escalate.

Miscellaneous Costs

This item includes administrative expenses and all expenses not covered under other categories. For the nuclear tanker it also includes the $25,000 annual nuclear license fee. These costs are estimated to be $940,000 and $965,000 for the fossil fueled and nuclear powered tankers, respectively. These costs are escalated at 8% per year for the lifetime of the ships.

Shore Staff Cost (Nuclear)

The nuclear ships will require several people to be included on the shore staff who are not included in the administrative expenses for the fossil fueled ship. It is assumed that a staff of 28 persons, full time, plus consultants at critical periods, will oversee the fleet of 21 ships. This cost is estimated to be $88,500 per ship per year and is escalated at 8% per year.

Inservice Inspection Cost (Nuclear)

In addition to the "baseline" inspection of the reactor coolant pressure boundary which is included in the predelivery costs, follow-on inspections are required every 2-1/2 years. To conform with the refueling overhauls, these inspections will be performed biannually. The estimated annual cost for these inspections is $108,000. This cost will be escalated at 8% per year.

Attrition Training Cost (Nuclear)

A 20% annual personnel attrition rate is assumed. The attrition training cost is estimated at $275,880 and represents 20% of the

initial training cost for one nuclear icebreaking tanker. These costs are expected to diminish over the life of the ship as more nuclear powered ships come into existence. No escalation is applied to this cost.

Nuclear Refueling Cost

The biannual refueling cost, excluding the cost of the nuclear fuel, is estimated to be $7,400,000. This cost is escalated at 8% per year. Table 5-12 shows a summary of the annual tanker operating expenses expressed in 1984 dollars.

Table 5-12

Summary of Projected Annual Tanker Operating Expenses

	Escalation Rate (%)	Fossil ($)	Nuclear ($)
Crew Cost	6	2,146,574	2,911,019
Stores and Supplies	8	600,000	600,000
Maintenance and Repair	8	1,465,000	1,950,000
Insurance:			
Protection and Indemnity		312,314	312,314
Hull and Machinery		3,093,750	5,006,250
Nuclear Liability			1,150,000
Miscellaneous	8	940,000	965,000
Extra Shore Staff	8		88,500
Inservice Inspections	8		108,000
Attrition Training			275,880
Refueling Cost (excluding nuclear fuel)	8		3,700,000

Terminal Operating Costs

These costs fall into the following categories: personnel pay and benefits, subsistence, maintenance and repair, stores and supplies, insurance, attrition training, utilities, taxes, administration, and

fleet support. All expenses are escalated at 8% per year for the life of the system.

Personnel Pay and Benefits - The Smith Bay terminal will have an operating complement of 83 persons. There will be 57 tower personnel and 26 shore-based personnel. The total annual cost is estimated at $2,300,000.

The FROST terminal will rotate two 91-man crews. The total annual cost is estimated at $5,044,000.

Subsistence - The subsistence cost is estimated at $50 per man per day. Therefore, the annual subsistence costs are $1,515,000 and $1,661,000 for the northern terminal and FROST, respectively.

Maintenance and Repair, Stores and Supplies - These costs are estimated to average about 2% per year of the initial construction cost. This amounts to $25,680,000 and $6,420,000 for the northern terminal and FROST, respectively.

Insurance - The insurance premium costs have also been estimated to be about 2% per year of the initial construction costs.

Attrition Training - A 20% annual personnel attrition rate is assumed. Based upon 20% of the salary for personnel during initial crew training plus instructors' wages, these costs are estimated at $218,000 and $488,000 for the Smith Bay terminal and FROST, respectively.

Utilities - The utility costs for the Smith Bay terminal are estimated at $800,000. This cost is much higher for the FROST and is estimated at $10,481,000. These higher costs arise because:

1. Fuel costs for pumping cargo are based on using cargo pumps totaling 20,000 HP, and are calculated as follows:

$$\text{Fuel Cost} = \frac{11{,}000 \text{ lb/hr}}{300 \text{ lb/bbl}} \times \$21.57/\text{bbl} \times 8700 \text{ hr/yr}$$

$$= \$6{,}881{,}000$$

2. An extra $3,600,000 fuel cost has been estimated for propulsion and services.

Taxes - This cost applies only to the Smith Bay terminal and is estimated at $9,000,000.

Administration, Fleet Support Allowance - This cost, estimated at $220,000, covers the administrative cost of the operator who operates and maintains the system. This cost applies only to the FROST.

Table 5-13 shows a summary of the annual terminal operating expenses expressed in 1984, delivery date, dollars.

Table 5-13

Summary of Projected Annual Terminal Operating Expenses

	Smith Bay (1984 $ Millions)	FROST
Personnel Pay and Benefits	2.300	5.044
Subsistence	1.515	1.661
Maintenance and Repairs, Stores and Supplies	25.680	6.420
Insurance	25.680	6.420
Attrition Training	.218	.488
Utilities	.800	10.481
Taxes	9.000	
Fleet Support		.220
Total Annual Operating Cost	65.193	30.734
Annual Operating Cost Per Ship	3.104	1.464

Annual Fuel Costs

The following data was used in this study for calculating the annual fuel costs of the competing tanker systems:

1977 Dollars	
Bunker C Fuel Oil	\$13.00/Barrel[21,22]
Nuclear Fuel	7 Mills/SHP-Hr[23]

These costs were then escalated at an annual rate of 7.5% over the lifetime of the ship. The price of Bunker C fuel oil used as the 1977 price base in this study is an "averaged" value. Currently, the actual average price of OPEC crude oil into the U.S. is approximately \$14.50 per barrel, and domestic crude oil is approximately \$11.50 to \$12.00 per barrel. The 1977 base price for nuclear fuel of 7 mills per SHP-Hr was verified using the fuel costing procedure outlined in reference 13. The core data and economic data utilized in this calculation are presented in Tables 5-14 and 5-15 below.

Table 5-14

Core Data[24]

Power (MWt)	314
Initial Loading (Kg U)	11,762
Enrichment (Average)	3.44%
Burnup (MWD/MTU)(Average)	14,400
(Maximum)	29,000
Discharge Loading (Kg U)	11,520
Fissile Plutonium Produced (Kg)	52.3
Effective Full Power Days	540

Table 5-15

Nuclear Fuel Economic Data[24,25]

	(1977 Dollars)
Feed Cost U_3O_8 ($/lb)	42
Conversion Cost $U_3O_8 \rightarrow UF_6$ ($/Kg)	4
Enrichment Cost ($/SWU)	61.30
Fabrication Cost, Average ($/Kg)	240
Reprocessing Cost ($/Kg)	215
Spent Fuel Shipping Cost ($/Kg U initial)	6
Plutonium Value ($/g)	13
Tails Assay (% ^{25}U)	.2

Sensitivity studies are run in Chapter VI to analyze the effects of varying this base price data.

The annual fuel cost for the fossil fueled tanker was calculated as follows:

$$\text{Annual Cost} = \frac{\$}{\text{BBL}} \times \frac{1}{\frac{\#(\text{Oil})}{\text{BBL}}} \times \frac{\#(\text{Oil})}{\text{SHP-Hr}} \times \text{PU} \times \text{SHP} \times \frac{\text{SD}}{\text{Yr}} \times \frac{\text{24-Hr}}{\text{Day}}$$

where:

$$\frac{\#(\text{Oil})}{\text{BBL}} = 338$$

$$\frac{\#(\text{Oil})}{\text{SHP-Hr}} = .477$$

PU = Plant Utilization Factor = .9

SHP = 240,000

$\frac{\text{SD}}{\text{Yr}}$ = Sea Days per Year = 303.4

The annual fuel cost for the nuclear powered tanker was calculated as follows:

$$\text{Annual Cost} = \frac{\text{Mills}}{\text{SHP-Hr}} \times \frac{\$}{10^3\text{Mills}} \times \text{SHP} \times \text{PU} \times \frac{\text{SD}}{\text{Yr}} \times \frac{\text{24-Hr}}{\text{Day}}$$

The annual fuel costs in 1984 (delivery date) dollars are estimated to be $47,878,000 and $17,875,000 for the fossil fueled and nuclear powered tankers, respectively. No allowance was made for fuel consumed in port.

Cargo Units Carried

The amount of cargo carried annually, i.e., the number of barrels of crude oil per voyage times the number of voyages per year, is different for the two competing tanker systems. The major reason for this difference is the fact that their cargo deadweights differ by approximately 24,000 LT. The prohibitive fuel requirements of the fossil fuel tanker cause this disparity (see Table 3-2).

Crude oil produced in the Arctic has densities ranging from 25° to 45° A.P.I., with the Alaskan crudes typically at the heavy end of this range. A density of 31° A.P.I (41.3 cubic feet per ton) was selected for this study. It is also assumed that the products from all wells supplying the loading terminal will be blended so that cargo density variations will be minimized. Because of this assumption only one "cargo segregation" will be required for the ship[2]. At a density of 31° A.P.I., one ton of crude oil is equivalent to 7.364 barrels. Each time the crude oil is handled during a transfer operation, some of it is lost. Although most of the oil is recovered by crude oil washing,

the net loss is approximately .2%-.4% by volume. This small loss, common to both icebreaking tanker systems, has been ignored in this study.

Fossil Fueled Icebreaking Tanker

For this ship the average annual cargo carried was determined as follows:

$$332.92 \ \frac{\text{Avail.Days}}{\text{Yr.}} \times \frac{1 \text{ Voy.}}{16.84 \text{ Days}} \times 224608 \ \frac{\text{LT}}{\text{Voy.}} \times 7.364 \ \frac{\text{BBL}}{\text{LT}} = 32{,}700{,}000 \ \frac{\text{BBL}}{\text{Yr.}}$$

Nuclear Powered Icebreaking Tanker

Similarly:

$$325.72 \ \frac{\text{Avail.Days}}{\text{Yr.}} \times \frac{1 \text{ Voy.}}{16.84 \text{ Days}} \times 248350 \ \frac{\text{LT}}{\text{Voy.}} \times 7.364 \ \frac{\text{BBL}}{\text{LT}} = 35{,}375{,}000 \ \frac{\text{BBL}}{\text{Yr.}}$$

This study assumes that the fossil fueled tanker burns Bunker C fuel oil during both legs of its voyage. Although it would be possible to burn crude oil on the southbound leg of the journey, it would be more dangerous because of the highly volatile and flammable characteristics of the crude oil. This type of fossil fueled ship would be considerably more expensive to build and thus was not considered during the course of this study[26].

Conventional Tanker Contribution to the System RFR

The detailed design and estimation of capital and operating costs of appropriate surface tankers, i.e., tankers suitable for use in transshipment from the FROST to East Coast terminals, was beyond the

scope of this study. However, since these costs cannot be excluded from the total system RFR, it was expedient to utilize current RFR's, as experienced by the oil companies, to account for the costs of the final leg of the voyage. U.S. flag RFR's are used for transporting crude oil which originates in Smith Bay, Alaska.

Currently no deep draft terminals exist anywhere along the U.S. East Coast, and none are planned within the foreseeable future. Therefore, Ultra or Very Large Crude Carriers (ULCC's or VLCC's) are not considered contenders for the role of the transshipment vessel in this study. The largest ship that can presently call at East Coast ports is approximately 125,000 DWT. This vessel carries about 800,000 barrels of crude oil and has a draft of 55 feet. A vessel possessing the above characteristics is used for this section of the economic analysis. Because of its relatively deep draft, the tanker must proceed to the Big Stone anchorage near Philadelphia to discharge a portion of its cargo, thus reducing its draft. To accomplish this, a barging company, e.g., Interstate Oil Transport Co., would be chartered to transfer about 400,000 barrels of crude oil from the tanker reducing its draft to approximately 37 feet. The tanker would then proceed to the Delaware River Terminal and discharge its remaining cargo[27].

Surface Tanker Cost

Mobil Shipping and Transportation Company provided RFR curves for U.S. flag surface tankers as a function of distance and deadweight tonnage. Newport News Shipbuilding then modified these curves to display RFR as a function of DWT for given distances[11]. Using the latter curves and assuming a surface tanker of 125,000 DWT, the surface

tanker RFR is estimated to be $1.54 per barrel in 1984 dollars.

Barging Cost

The barging cost is estimated to be $.31 per barrel in 1984 dollars.

Port Charges

This cost is estimated to be $14,000 in 1984 dollars or about $.03 per barrel.

Table 5-16 summarizes the conventional surface tankers' contribution to the total system RFR.

Table 5-16

Surface Tanker Contribution to System RFR
(1984 Dollars)

	RFR ($/BBL)
125,000 DWT Tanker	1.54
Barging Costs	.31
Port Charges	.03
Total	1.88

Results

System required freight rates were calculated for the reference case using the economic models contained in Appendices A and B for the nuclear powered and fossil fueled icebreaking tanker transportation

systems, respectively. Table 5-17 summarizes the results of the reference case analysis.

Table 5-17

System Required Freight Rates--Reference Case
($/BBL)

	System RFR
Nuclear Powered Icebreaking Tanker System	9.35
Fossil Fueled Icebreaking Tanker System	10.30

These results compare very favorably with the estimated tariff from Prudhoe-Valdez-Panama Canal-U.S. East Coast of $15.00 per barrel. The RFR from Prudhoe to Valdez via the Alaskan pipeline is estimated at $6.00 per barrel. The RFR from Valdez to the Delaware River Terminal via the Panama Canal is estimated at $3.86 per barrel in 1984 dollars, including Panama Canal fees. This rate is escalated at 8% per year over the life of the system. After applying present worth techniques to this portion of the RFR and adding it to the pipeline tariff, the system average RFR equals $15.00 per barrel[28].

Table 5-17 shows that while both icebreaking tanker systems are economically superior to the pipeline system, the nuclear system enjoys an advantage of about 9% over its fossil fueled counterpart. This modest advantage gains added significance when one recalls that these reference figures were developed assuming icebreaking tanker fleets of

equal size. In fact, the fossil system requires two additional icebreaking tankers to deliver the same annual design steady state system throughput of 730 million barrels. This requirement for two additional tankers adds about 7.8% to the fossil fueled icebreaking tanker system RFR. Thus it appears that the nuclear powered icebreaking tanker system enjoys an economic advantage of approximately 17%. The following chapter, Economic Analyses: Sensitivity Studies, analyzes the effects of varying many of the key input variables assumed for the reference case study.

VI. ECONOMIC ANALYSES: SENSITIVITY STUDIES

Sensitivity studies were conducted, changing one input variable at a time, to show the effects on the comparison of the nuclear system RFR versus the fossil system RFR. The effects of varying the following parameters are investigated:

- Operating Cost Escalation
- Capital Cost Escalation
- Construction Differential Subsidy
- Nuclear Propulsion Plant Cost
- Terminal Construction Costs
- Nuclear Fuel Cost and Escalation Rate
- Bunker C Fuel Oil Cost and Escalation Rate
- Ship Life
- Bank Interest Rate
- Debt to Capital Ratio

Operating Cost Escalation

In the reference case, operating costs are escalated as shown in Table 5-12. If operating costs are expressed in 1984 dollars (assumed delivery date) with no subsequent operating cost escalation, the results of the economic analyses are as follows:

	RFR ($/BBL)
Nuclear System	5.63
Fossil System	5.56

The RFR for both systems has decreased significantly as expected. The percentage decrease for the fossil system was greater, however, because a higher fraction of its total annual costs was concentrated in the area of operating costs. In this case, the fossil system enjoys an apparent advantage of about 1.25%. The word "apparent" is important here because it must be remembered that the fossil system requires two additional icebreaking tankers to transport the same design system throughput. This extra fleet requirement would increase the fossil system annual operating costs by approximately 8.5%. Thus it is clear that the nuclear system remains economically competitive even when operating costs are not escalated throughout the life of the system.

Capital Cost Escalation

Capital cost escalation in the reference case study is assumed to be 8% per year. Figure 6-1 shows the effect of varying this escalation rate from 0% to 30% annually. It should be noted in Figure 6-1 that the y-axis is displaced from zero at the origin. This has been done to better emphasize the effects of the parameter variation. This same technique is used for the remaining figures in this chapter.

The reference case study assumes that the contract for both the nuclear and the fossil icebreaking tankers includes a base price expressed in 1978 dollars with a provision for cost escalation to the date of each progress payment. Figure 6-1 shows that the nuclear system is preferred for all realistic estimates of capital cost escalation. In fact, the crossover point is not reached until capital cost escalation soars to approximately 30%. Should the escalation rate be less

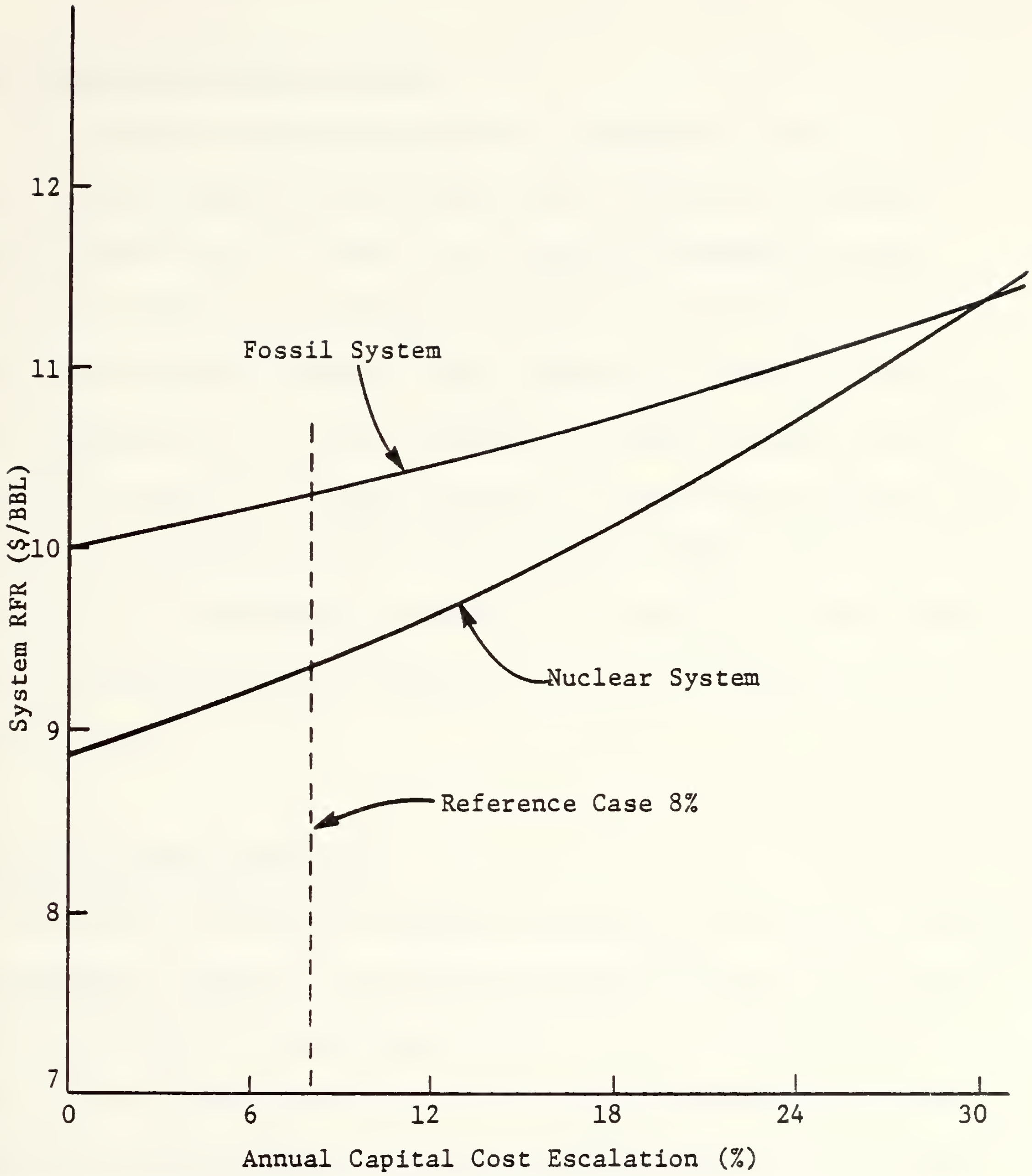


Figure 6-1

Effects of Capital Cost Escalation on RFR

than the reference case value of 8%, the relative advantage of the nuclear system increases as indicated.

Construction Differential Subsidy

The reference case study assumes no governmental support of any kind for either transportation system other than the very minimal training support for the crews of the nuclear icebreaking tankers. One possible method of governmental support is in the form of a construction differential subsidy (CDS). Figure 6-2 shows the effects of a CDS ranging from 0% to 35%, currently the maximum allowed by law. Any amount of CDS will decrease the RFR for both systems; however, the net effect is greater for the nuclear system, because a higher percentage of its total RFR is attributable to acquisition costs. Therefore, any amount of CDS will enhance the relative advantage of the nuclear system.

Nuclear Propulsion Plant Cost

The cost of the nuclear propulsion plant can be favorably affected by governmental support in the form of a Nuclear Incentive Allowance or adversely affected by construction cost overruns. Figure 6-3 illustrates both of these possibilities. The nuclear incentive allowance represents an extraordinary form of governmental financial assistance which has been proposed for the first few nuclear merchant ships to encourage the use of nuclear power in the merchant marine[4]. The reference case, however, assumes no nuclear incentive allowance. Figure 6-3 shows that the nuclear system RFR decreases to $8.84/barrel

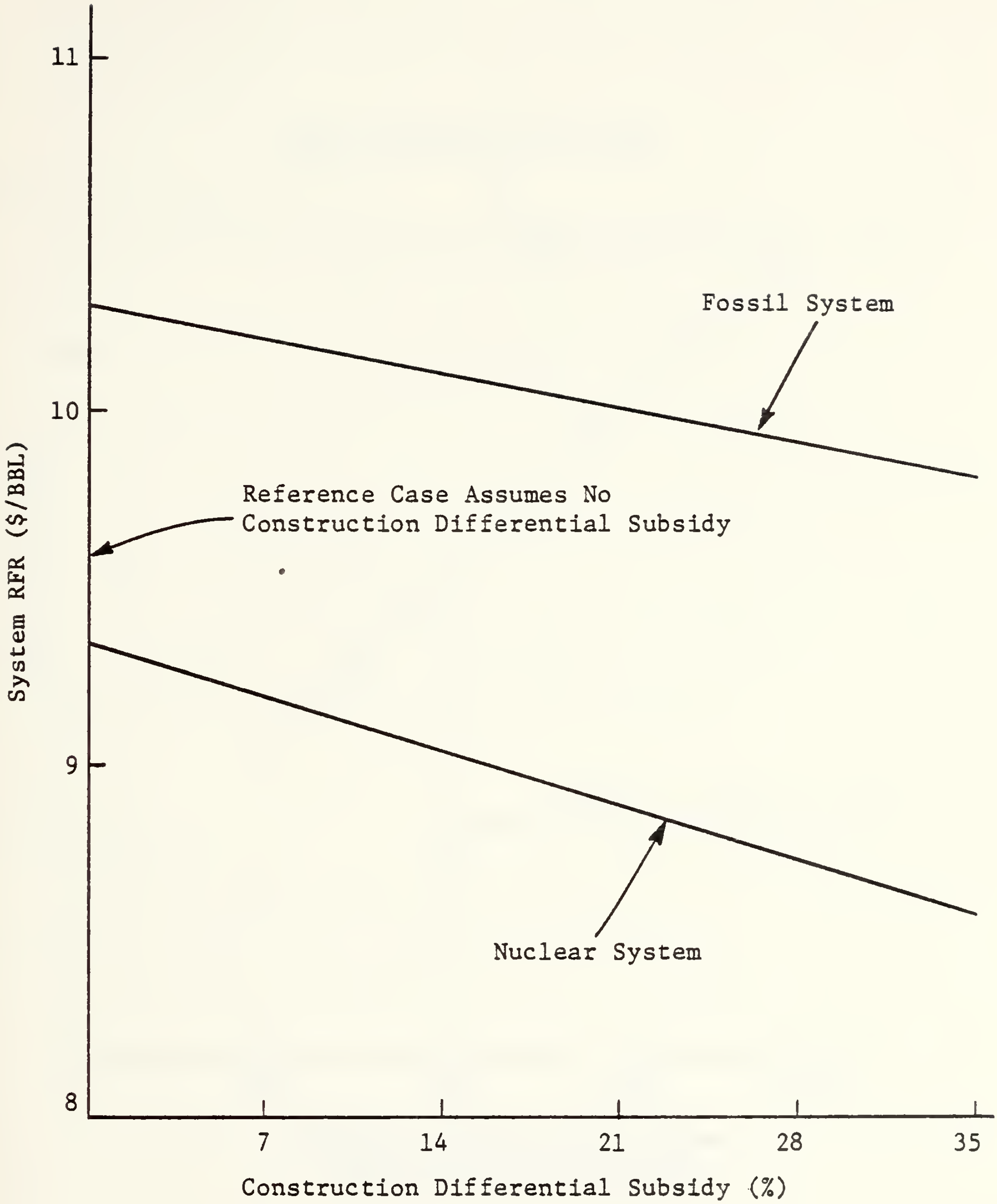


Figure 6-2

Effects of Construction Differential Subsidy on RFR

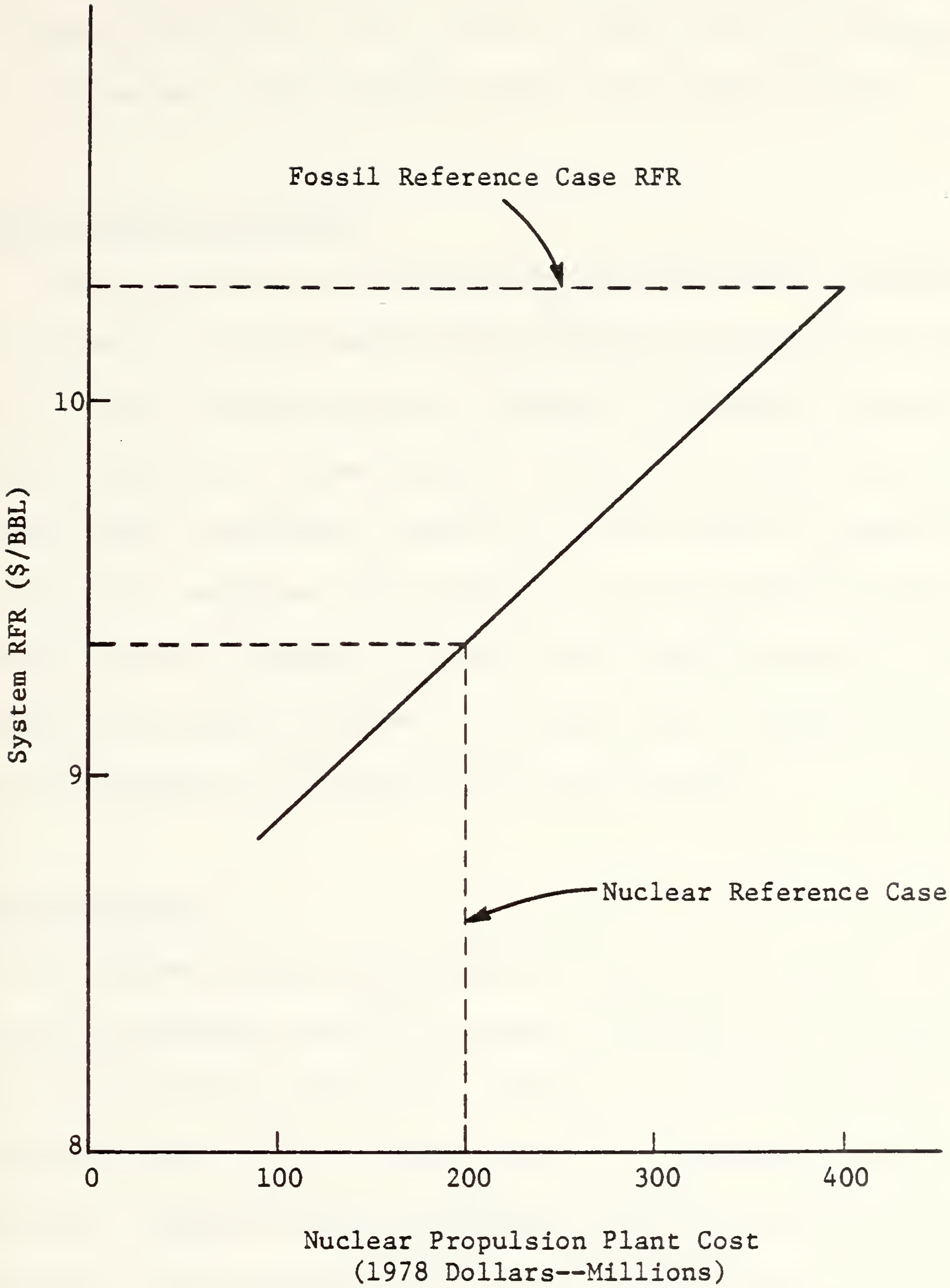


Figure 6-3

Effects of Nuclear Propulsion Plant Cost on RFR

if the cost of both CNSG's is defrayed by the government, and to $9.10/barrel if the cost of only one CNSG is governmentally supported. It should be noted that a cost overrun of $200 million is required to force the nuclear system RFR above that of the fossil system.

Terminal Construction Costs

The construction costs for the northern and mobile terminals were estimated at approximately $1613 million in the reference case study. These costs were the most difficult to estimate because of the extreme uniqueness of these projects. Figure 6-4 shows that both systems remain economically viable over a wide range of terminal construction cost estimates. The effect on the total RFR for both systems is nearly identical. However, the nuclear system RFR increases slightly more rapidly, because the terminal costs represent a relatively higher percentage of the total RFR for that system.

Nuclear Fuel Cost

The reference case study assumes a nuclear fuel cost of 7 mills per shaft horsepower hour (1977 dollars), escalated at an annual rate of 7.5% for the life of the ship. Figure 6-5 shows the effects of varying the basic fuel cost value from 5 to 15 mills per shaft horsepower hour. Although the reference case value of 7 mills per SHP-Hr. is thought to be conservative, it should be noted that the nuclear fuel cost can increase to approximately 13 mills per SHP-Hr. before the fossil system gains the economic advantage. Figure 6-6 shows the effects of varying the annual escalation rate of the nuclear fuel cost,

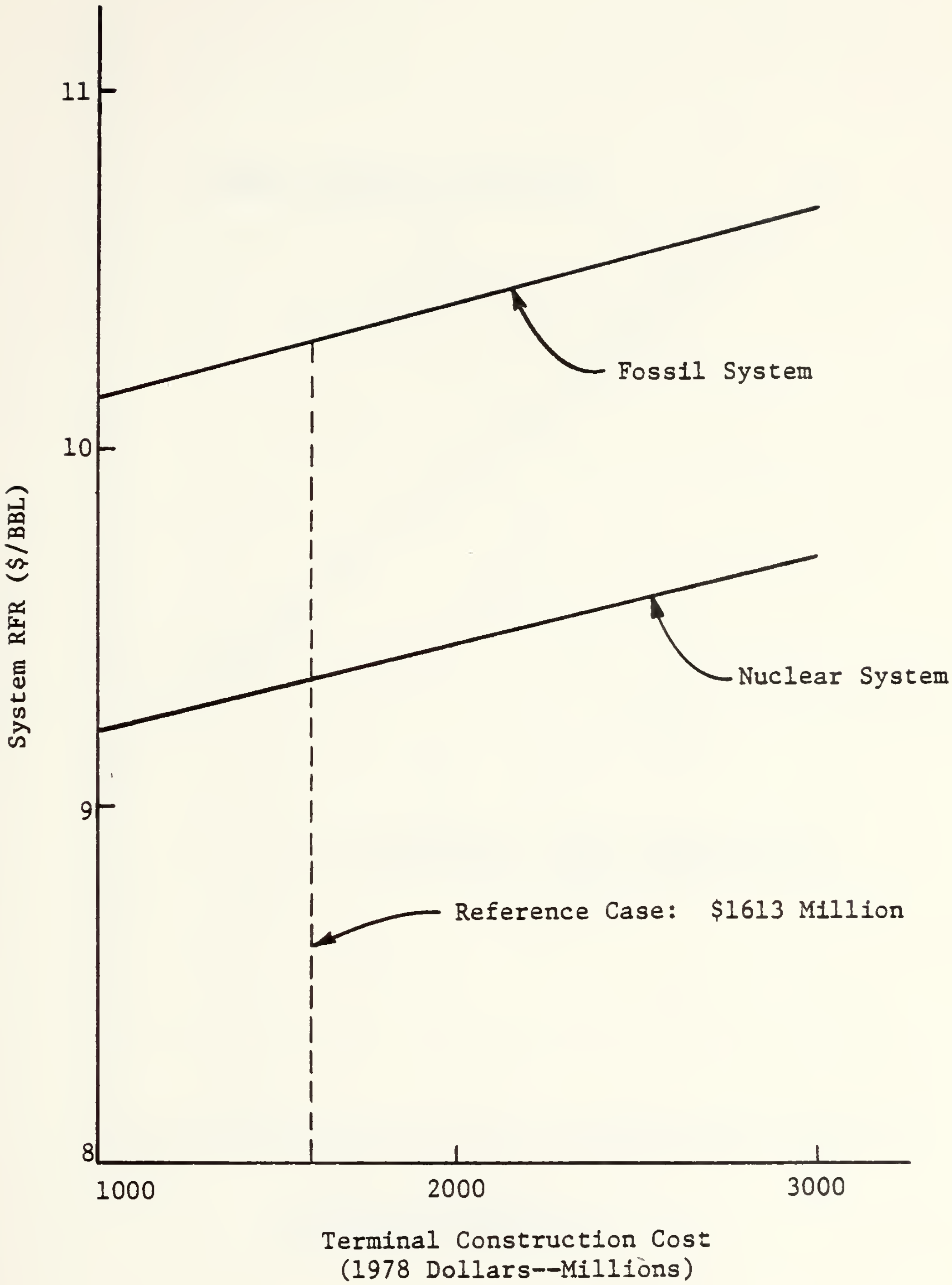


Figure 6-4

RFR Variation Due to Terminal Construction Cost

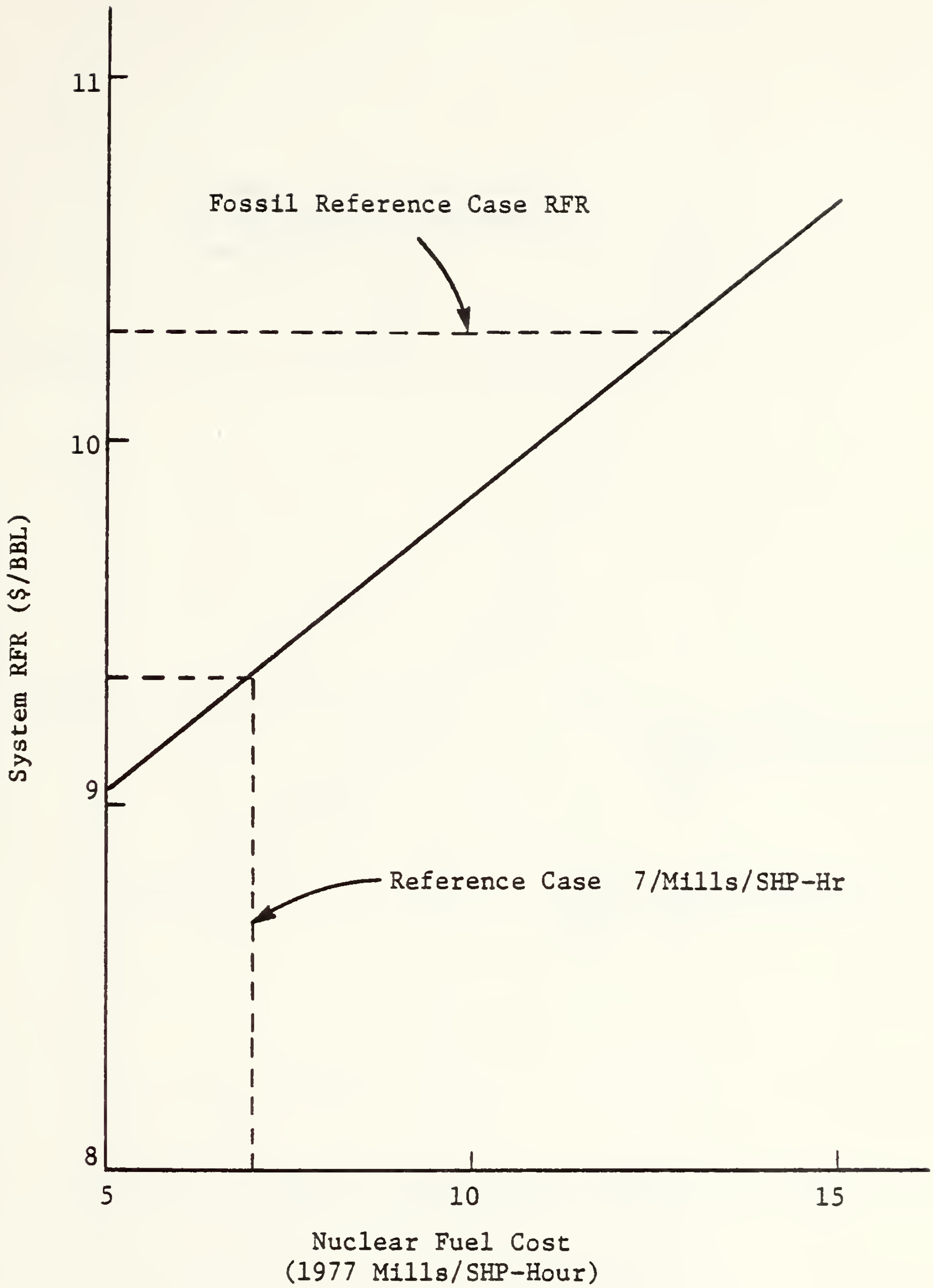


Figure 6-5

RFR as a Function of
Nuclear Fuel Cost

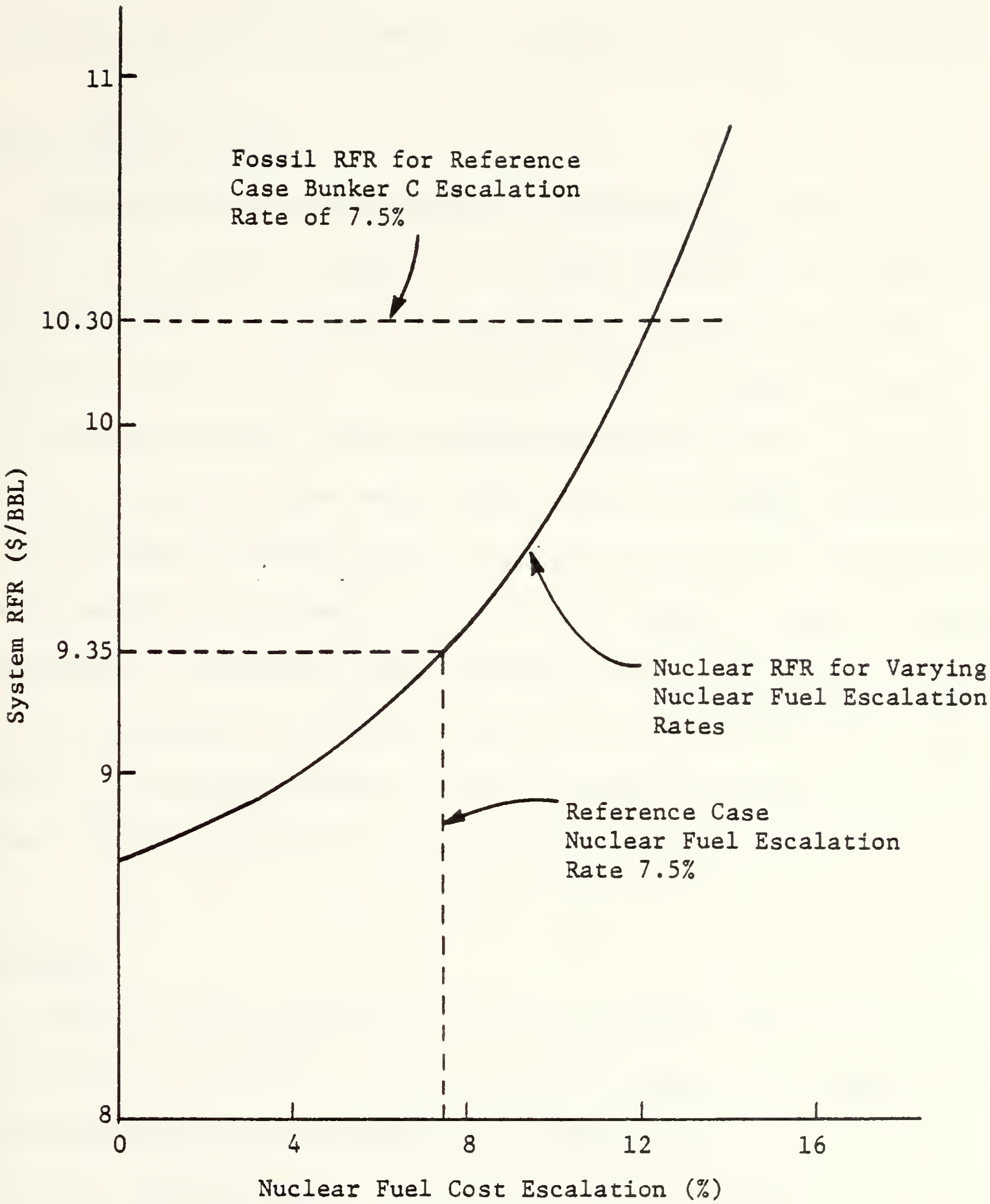


Figure 6-6

RFR as a Function of the
Nuclear Fuel Cost Escalation Rate

given that the initial fuel cost is 7 mills per SHP-Hr. (1977 dollars). The nuclear system retains the economic advantage until the annual escalation rate for the nuclear fuel exceeds 12.4%.

Bunker C Fuel Oil Cost

The reference case study assumes a fossil fuel oil cost of $13 per barrel (1977 dollars), escalated at an annual rate of 7.5%. Figure 6-7 shows the effects of varying the basic Bunker C fuel oil cost value from $10 to $20 per barrel. It is evident from the figure that even if the price of Bunker C fuel oil should inexplicably drop to $10 per barrel, the nuclear system would still retain the economic advantage. Clearly any price increase above the reference value of $13 per barrel greatly enhances the advantage of the nuclear system. Figure 6-8 shows the effects of varying the annual escalation rate of the Bunker C fuel oil cost, given that the initial fuel oil cost is $13 per barrel (1977 dollars). The nuclear system retains the economic advantage until the annual escalation rate for the fossil fuel drops below 4.5%.

Ship Life

The life of the icebreaking tankers is assumed to be 25 years for the reference case study. Although this is intended to be a minimum, the sensitivity study investigated both longer and shorter lifetimes. Figure 6-9 shows the effects of varying the ships' lifetimes and thus the length of their amortization periods. Two counteracting forces come into play in this analysis. First, the shorter ship life tends to increase the total RFR for both systems, because the shorter

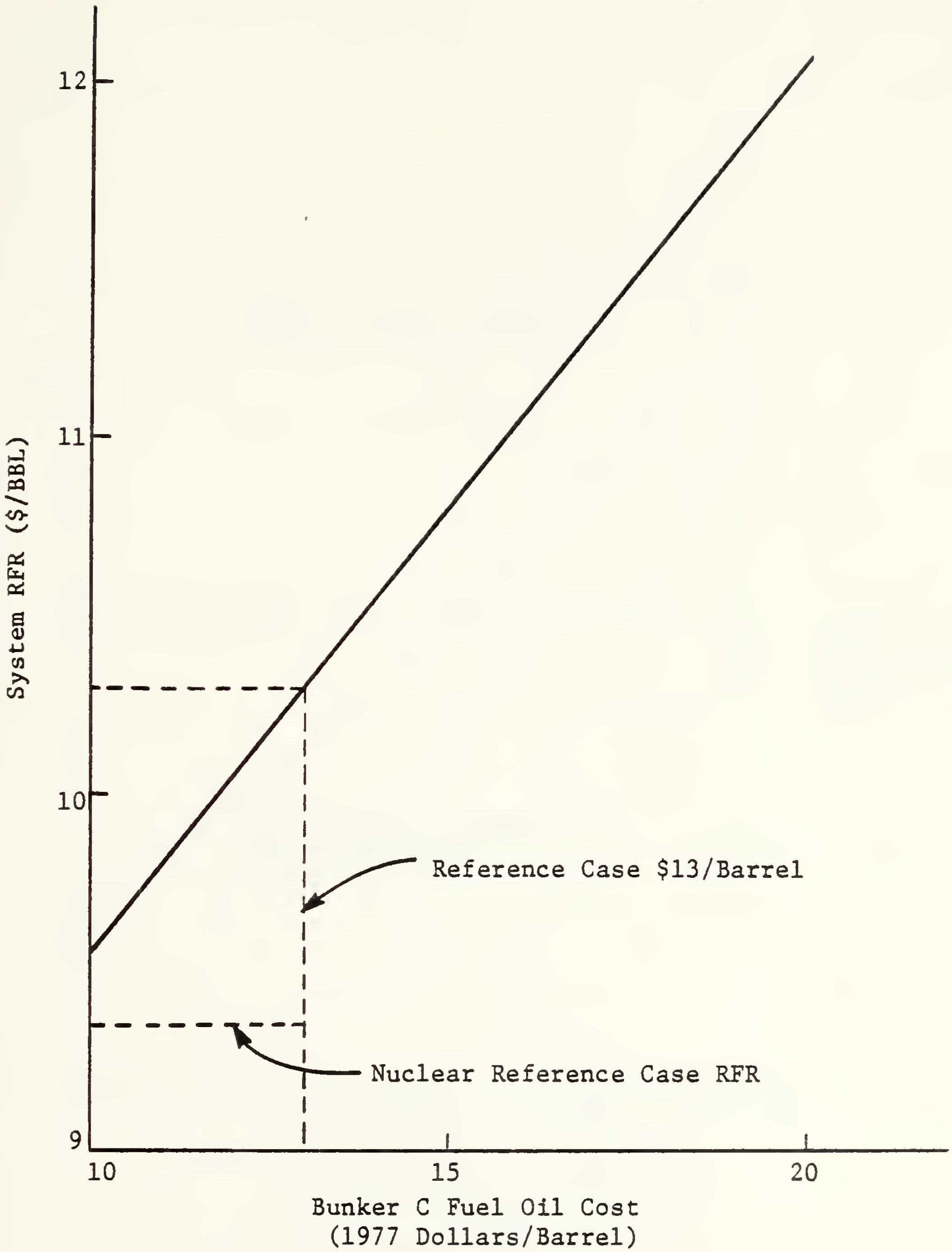


Figure 6-7

Effects of Varying the Bunker C Fuel Oil Cost on RFR

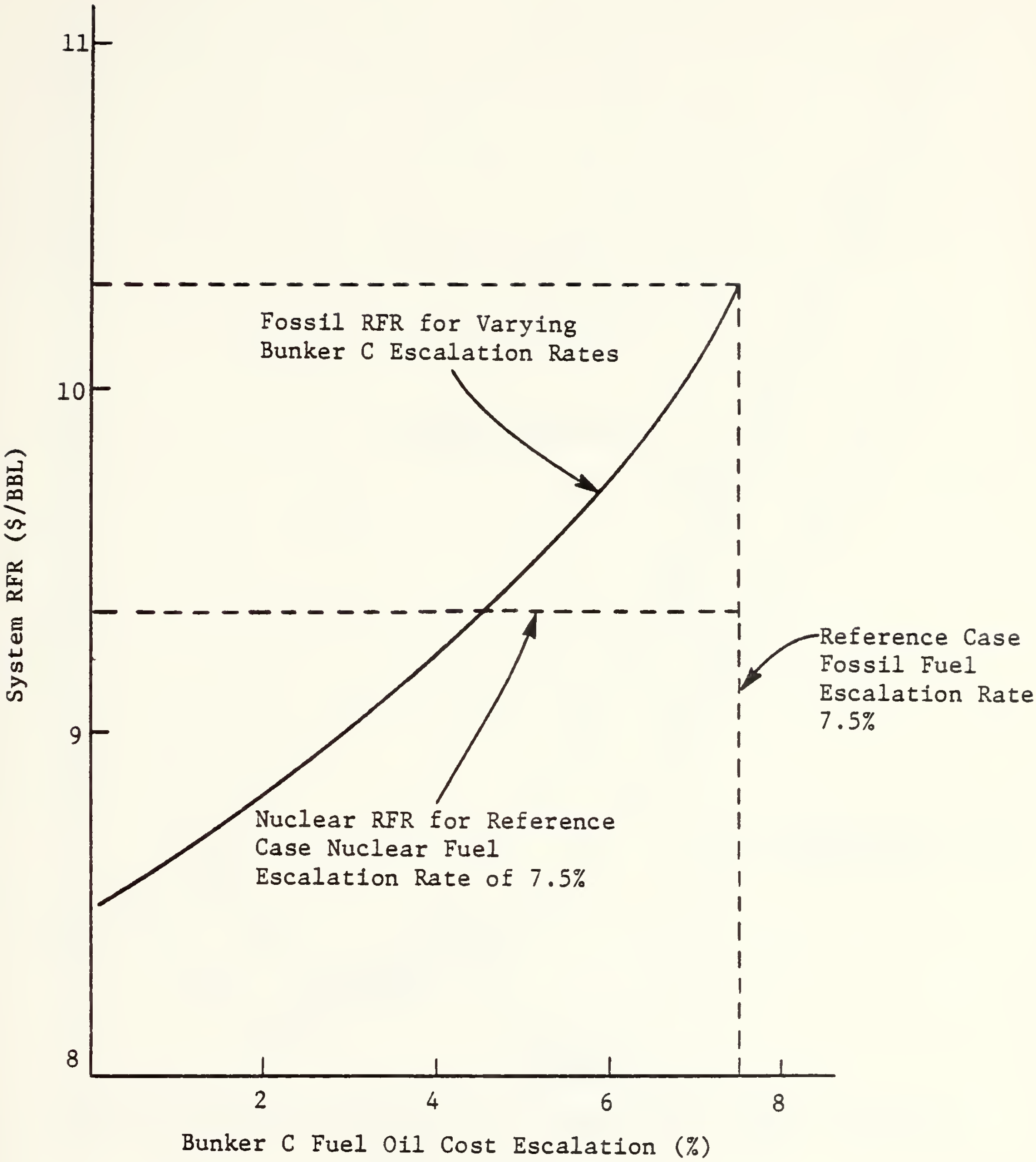


Figure 6-8

RFR as Affected by the Bunker C
Fuel Oil Cost Escalation Rate

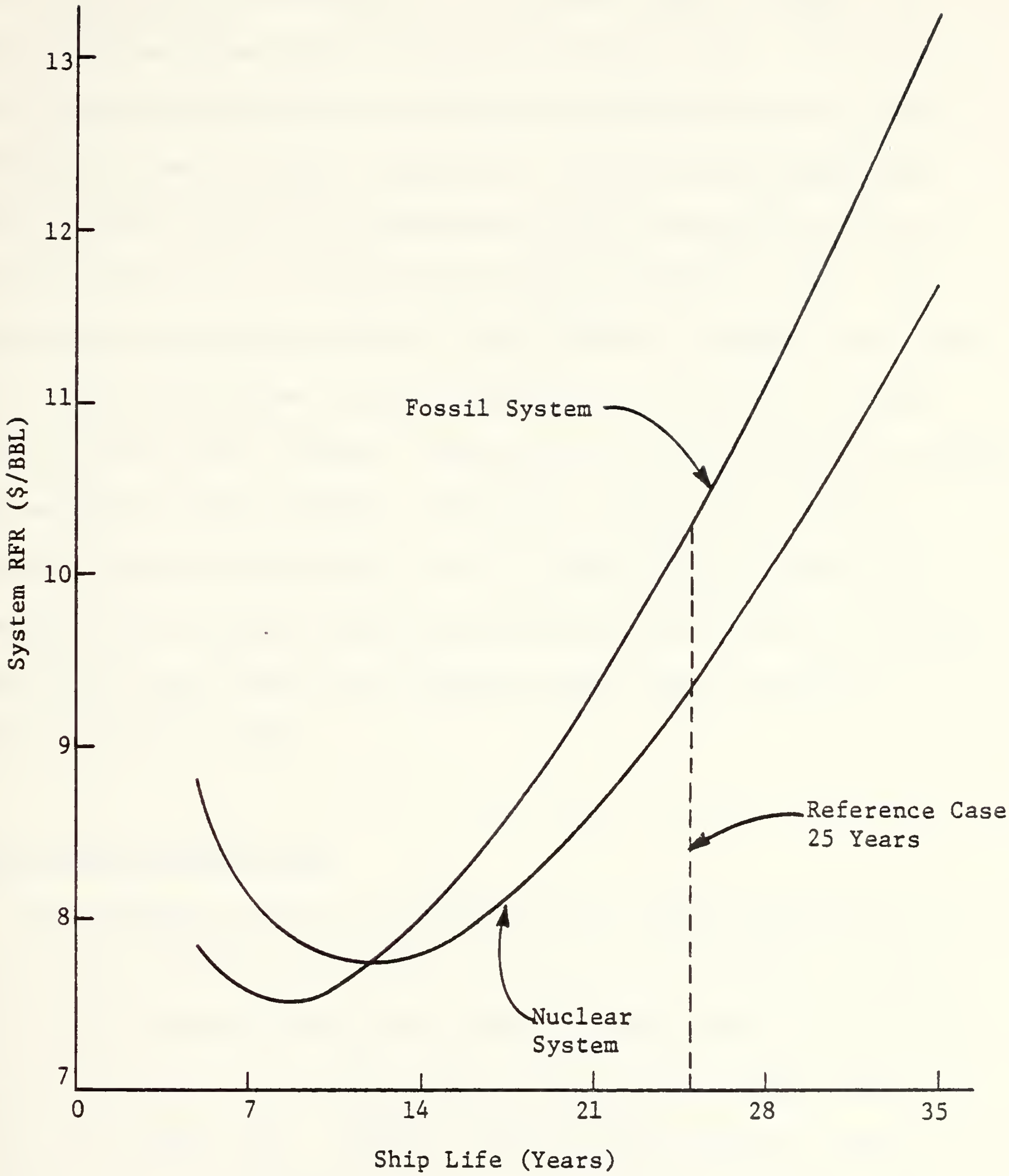


Figure 6-9

Effects of the Time of Ship Amortization on RFR

amortization period causes the annual capital recovery costs to increase rapidly. Secondly, the longer ship life also tends to increase the total RFR for both systems but for a different reason. Namely, the longer lifetime gives rise to increased operating costs. The sum of the decreasing acquisition cost RFR and the increasing operating cost RFR yields curves as shown on Figure 6-9. These curves display high RFR's for short service lives (because of high acquisition cost), and for long service lives (because of the higher operating costs). The theoretical minimum value for each curve occurs at a shorter than normal life. The actual optimal service life does not occur at the minimum point on these curves, however. Operating costs will inevitably increase independently of ship lifetime. Therefore, prospective shipowners desire to operate their ships as long as safety considerations will prudently allow, thereby decreasing the annual cost of capital recovery. Figure 6-9 clearly shows that increased service lives economically favor the nuclear tanker.

Bank or Bond Interest Rate

The reference case study assumes a bank or bond interest rate of 9%. Figure 6-10 shows the effects of varying this interest rate from 6% to 25%. This figure shows that higher interest rates are relatively more detrimental to the nuclear system because of the higher capital cost of the nuclear ship. However, over the entire range of realistic interest rates, the nuclear ship enjoys the economic advantage. The crossover point is not reached until the interest rate rises to an exorbitant level of 24.5%.

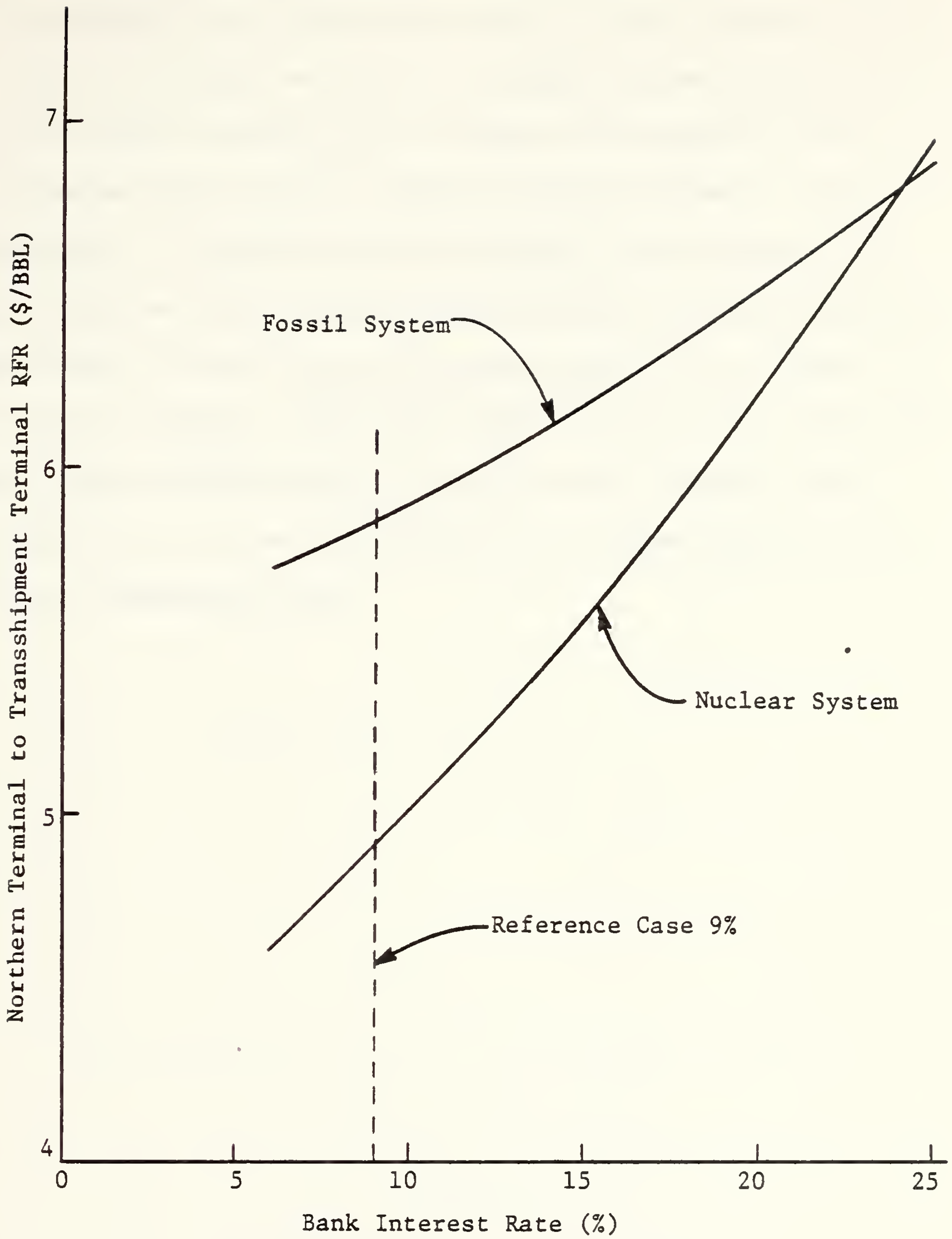


Figure 6-10

Effects of Varying Bank or Bond Interest Rate on Tanker RFR

Debt to Total Capital Ratio

The reference case study assumes a debt to total capital ratio of .75. Figure 6-11 shows the effects of varying this ratio from 0.0 to 1.0. As the debt to capital ratio increases, the effective cost of money decreases due to the tax credits on interest payments that are tax deductible. In addition, the debt interest rate assumed in the reference case was lower than the assumed equity return rate; therefore, at higher debt to capital ratios, the lower interest rate reduces the effective cost of money. Figure 6-11 shows that the nuclear tanker RFR is lower than the fossil tanker RFR for all debt to capital ratios above about .20. This was expected due to the higher capital cost of the nuclear icebreaking tanker.

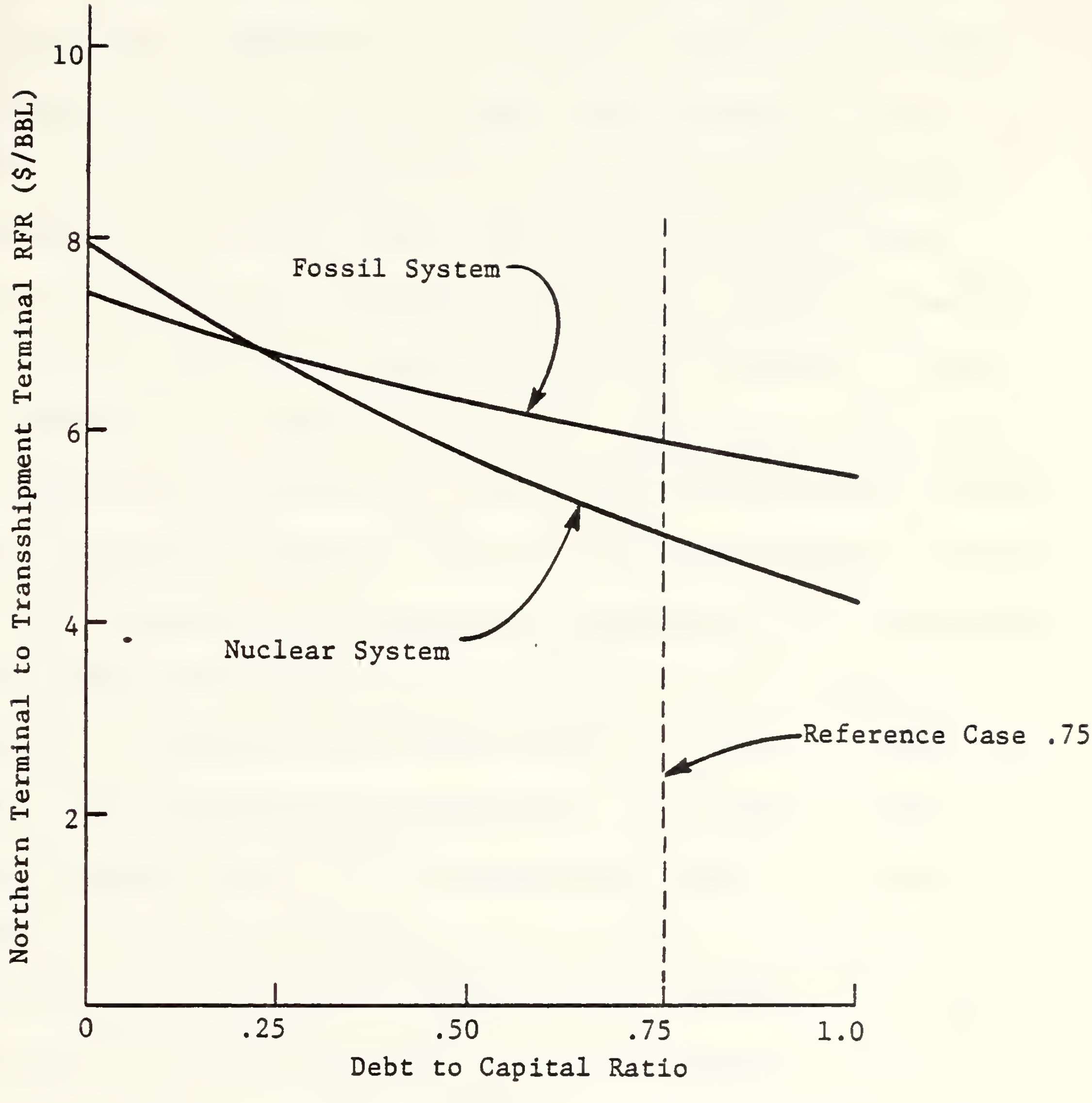


Figure 6-11

Variation of Debt to Total Capital
Ratio and Its Effect on Tanker RFR

VII. SUMMARY AND RECOMMENDATIONS

This study has presented an economic analysis of the total cost of acquiring, owning, and operating an Arctic icebreaking tanker transportation system. Specifically, two competing systems were analyzed for economic viability. The two systems were identical with the exception of the icebreaking tanker fleets. One system utilized a nuclear powered icebreaking tanker fleet, while the other system utilized a fossil fueled icebreaking tanker fleet. Chapters I and II introduce the scope of the paper and discuss the conclusions of the study, respectively. Chapter III briefly describes each component of the transportation system used for this economic analysis and discusses possible alternative systems. Chapter IV details the economic criteria used in the economic model formulation. Appendices A and B contain the computer programs developed using the economic criteria contained in Chapter IV. A reference case economic study is analyzed in detail in Chapter V. The reference case is designed to illustrate the most probable economic future of the transportation system. As pointed out in Chapter V, the nuclear system enjoys an economic advantage of approximately 17%, assuming the reference case assumptions hold true. Because many of the input variables are very difficult to accurately assess, Chapter VI summarizes the results of sensitivity study analyses which varied the key input variables above and below their reference case values.

This study vividly points out the economic competitiveness of the nuclear icebreaking tanker transportation system; however, this is not

enough. Further study and research must be actively and vigorously pursued in the following areas:

1. Terminal design including both the northern loading terminal and the transshipment terminal, including site studies.
2. Environmental studies.
3. Safety studies.
4. Economic studies - other propulsion combinations, ship displacements, and transshipment options should be evaluated.
5. Model studies.
6. Ice studies.

The need for crude petroleum is real and today's energy crisis vividly attests to that fact. The <u>absolute</u> need for this transportation system is, perhaps, a few years away. However, research and development in this critical area must continue expeditiously so that the challenge can be adequately met in the not too far distant future.

BIBLIOGRAPHY

1. The Wall Street Journal. 26 September, 1977.

2. "Maritime Conceptual Design Study for Nuclear Powered Icebreaking Tanker Transportation System." MarAd Contract No. 5-38022, study performed by Newport News Shipbuilding, Newport News, Virginia, January 1977.

3. "Nuclear Maritime--An Economic Revival." R. W. Dickinson, S. H. Esleeck, J. E. Lemon. Paper presented at the Spring Meeting of the Society of Naval Architects and Marine Engineers, Williamsburg, Virginia, 24-27 May, 1972.

4. "Maritime Design Study for 600,000 DWT Nuclear Tanker." Volume 5 of 5, Economic Evaluation, MarAd Contract No. 5-38022, study performed by Newport News Shipbuilding, Newport News, Virginia, August 1976.

5. "Arctic Resources by Sea." Canadian Ministry of Transport, study performed by Northern Associates (Holdings) Ltd., Montreal, Quebec, Canada, July 1973.

6. "Herschel Island: Feasibility of a Marine Terminal." Department of Public Works, Ottawa, Canada, 1970.

7. "Economically Competitive Submarine Transport Systems for Arctic Basin Oil." U.S. Maritime Administration, Washington, D.C., March 1973.

8. "Advances in the Development of Commercial Ice-Transiting Ships." George H. Levine, Richard P. Voelker, Paul B. Mentz. Paper presented at Annual Meeting of the Society of Naval Architects and Marine Engineers, New York, N.Y., 14-16 November 1974.

9. "The Feasibility of an Icebreaking Nuclear Powered Tanker Transportation System for Alaska to East Coast U.S. Ports." Alvin O. Winall, Zelvin Levine, paper presented at Annual Meeting, Offshore Technology Conference, Houston, Texas, 2-5 May, 1977.

10. "North Slope Oil and Gas Transportation Study: FROST." Advanced Systems Design Group, J. C. Michie III, Joseph D. Deal, Jr., Newport News Shipbuilding, Newport News, Virginia, 1 October, 1970.

11. "Arctic Submarine Tranportation System-1975." Volume 5 of 7, Cost Analysis, MarAd Contract No. 4-37032, study performed by Newport News Shipbuilding, Newport News, Virginia, 1975.

12. "Economic Criteria for Decision Making in the Transportation Industry." Harry Benford, University of Michigan, Ann Arbor, Michigan, May 1966.

13. "Fuel Management Course Notes." Warren F. Witzig, The Pennsylvania State University, Department of Nuclear Engineering. Summer, 1976, University Park, Pennsylvania.

14. "Fundamentals of Ship Design Economics." Harry Benford, University of Michigan, Ann Arbor, Michigan, May 1970.

15. "Economic Comparison of a Nuclear Powered and Fossil Fueled Container Ship." T. B. Dade, M.S. Paper, Department of Nuclear Engineering, The Pennsylvania State University, University Park, Pennsylvania, April 1972.

16. "Fuel Cycle Economics." Daniel F. Hang, University of Illinois, October 1970.

17. "Economic Analysis of the Nuclear Fuel Cycle, Including Pre- and Post-Reactor Periods." V. P. Zodiaco, M.S. Thesis, Department of Nuclear Engineering, The Pennsylvania State University, University Park, Pennsylvania, December 1971.

18. "Environmental Impact Analysis--Nuclear Merchant Ship Program." Volume 3 of 3, Maritime Administration Study prepared by NUS Corporation, Rockville, Maryland, March 1975.

19. "Design and Economic Analysis of Nuclear Propulsion LNG Tankers." MarAd Contract No. 4-37112, study performed by Alexander Marine Associates, New Orleans, Louisiana, 25 March, 1975.

20. "Nuclear Ship Economic Considerations." Babcock and Wilcox Technical Paper, July 1975.

21. Phonecon. Mr. Edward Biddle, Defense Fuel Supply Center, Cameron Station, Alexandria, Virginia, 8 July, 1977.

22. Phonecon. Mr. Glen Burk, Union Oil Company, 11 July, 1977.

23. Phonecon. Mr. S. H. Esleeck, Babcock and Wilcox Corporation, 7 September, 1977.

24. Phonecon. Mr. S. H. Esleeck, Babcock and Wilcox Corporation, 24 October, 1977.

25. Phonecon. Mr. Dan Collier, Nuclear Assurance Corporation, Atlanta, Georgia, 1 July, 1977.

26. Phonecon. Mr. J. P. Jones, Mobil Shipping and Transportation Company, 12 August, 1977.

27. Phonecon. Mr. Pat Callahan, Mobil Shipping and Transportation Company, 29 September, 1977.

28. Phonecon. Transportation Analyst, Mobil Shipping and Transportation Company, 3 November, 1977.

APPENDIX A

COMPUTER CODE

ECONOMIC ANALYSIS

NUCLEAR POWERED ICEBREAKING

TANKER TRANSPORTATION SYSTEM

REFERENCE CASE PROGRAM

```
C  THIS PROGRAM COMPUTES THE REQUIRED FREIGHT RATE FOR AN ARCTIC ICEBREAK
C  ING TANKER TRANSPORTATION SYSTEM WHICH UTILIZES A NUCLEAR  FUELED
C  ICEBREAKING TANKER FLEET, A MOBILE TRANSSHIPMENT TERMINAL AND A
C  CONVENTIONAL SURFACE TANKER FLEET TO TRANSPORT CRUDE OIL FROM THE
C  ALASKAN NORTH SLOPE TO THE EAST COAST OF THE UNITED STATES.
C
C  AAC             =  TOTAL AVERAGE ANNUAL COST OF ICEBREAKING TANKER AND
C                     TERMINALS IN DOLLARS
C  AAOC            =  AVERAGE ANNUAL OPERATING COST
C  ACC             =  ANNUAL CREW COST IN DOLLARS
C  AFC(I)          =  ANNUAL FUEL COST FOR YEAR (I) IN DOLLARS
C  AVD             =  SHIP AVAILABILITY IN DAYS PER YEAR
C  B               =  DEBT TO TOTAL CAPITAL RATIO
C  BBLVOY          =  NUMBER OF BARRELS OF CRUDE OIL CARRIED PER VOYAGE
C  BI              =  BANK OR BOND INTEREST RATE
C  CAOC            =  CUMULATIVE ANNUAL OPERATING COSTS (PRESENT VALUE OF
C                     FUEL PLUS OPERATING COSTS) IN DOLLARS
C  CAPS            =  AVERAGE ANNUAL SHIP ACQUISITION COSTS IN DOLLARS
C  CAPT            =  AVERAGE ANNUAL TERMINAL ACQUISITION COSTS IN DOLLARS
C  CATR            =  ANNUAL COST OF CREW ATTRITION TRAINING IN DOLLARS
C  CH              =  BUDGETARY ESTIMATE FOR HULL COST IN DOLLARS
C  CISI            =  FIRST YEAR INSERVICE INSPECTION COST IN DOLLARS
C  CONRFR          =  AVERAGE ANNUAL RFR FOR CONVENTIONAL TANKERS ($/BBL)
C  CRFR            =  FIRST YEAR RFR FOR CONVENTIONAL TANKER FLEET ($/BBL)
C  CRFU            =  FIRST YEAR REFUELING COST IN DOLLARS
C  CRN             =  BUDGETARY ESTIMATE FOR THE NSSS IN DOLLARS
C  CRF(X,T)        =  CAPITAL RECOVERY FACTOR AT RATE X FOR T YEARS
C                     BEFORE TAXES
C  CRFT(X,DT)      =  CAPITAL RECOVERY FACTOR AT RATE X FOR DT YEARS
C                     AFTER TAXES
C  CRFTT(X,DTT)    =  CAPITAL RECOVERY FACTOR AT RATE X FOR DTT YEARS
C                     AFTER TAXES
C  CSHPHR          =  COST OF NUCLEAR FUEL IN DOLLARS PER SHP HOUR
C  DPVOY           =  NUMBER OF DAYS PER VOYAGE INCLUDING TURNAROUND TIME
C  DT              =  TIME IN YEARS OVER WHICH THE SHIP IS DEPRECIATED
```

```
C   DTT          =  TIME IN YRS OVER WHICH THE TERMINALS ARE DEPRECIATED
C   ECCISI       =  ESCALATION RATE FOR COST OF INSERVICE INSPECTIONS
C   ECCRFU       =  ESCALATION RATE FOR COST OF REFUELING
C   ECESS        =  ESCALATION RATE FOR COST OF EXTRA SHORE STAFF
C   ECL          =  ESCALATION RATE FOR COST OF LABOR
C   ECMAR        =  ESCALATION RATE FOR COST OF MAINTENANCE AND REPAIR
C   ECMIS        =  ESCALATION RATE FOR COST OF MISCELLANEOUS EXPENSES
C   ECNF         =  ESCALATION RATE FOR COST OF NUCLEAR FUEL
C   ECON         =  ESCALATION RATE FOR COST OF CONSTRUCTION
C   ECSAS        =  ESCALATION RATE FOR COST OF STORES AND SUPPLIES
C   ECVE         =  ESCALATION RATE FOR COST OF TERMINAL OPERATIONS
C   ER           =  EQUITY RETURN RATE
C   ERX          =  ESCALATION RATE FOR COST OF NSSS
C   ESS          =  FIRST YEAR COST FOR EXTRA SHORE STAFF IN DOLLARS
C   HAM          =  ANNUAL COST FOR HULL AND MACH. INSURANCE IN DOLLARS
C   MAR          =  FIRST YEAR COST OF MAINTENANCE AND REPAIR IN DOLLARS
C   MIS          =  FIRST YEAR COST OF MISCELLANEOUS EXPENSES IN DOLLARS
C   NLI          =  ANNUAL COST OF NUCLEAR LIABILITY INSUR. IN DOLLARS
C   NOBBL        =  NUMBER OF BARRELS OF CRUDE OIL CARRIED PER YEAR
C   PAI          =  ANNUAL COST OF PROT. AND INDEM. INSURANCE IN DOLLARS
C   PRFR         =  PRESENT VALUE OF CONVENTIONAL TANKER RFR ($/BBL)
C   PU           =  PLANT UTILIZATION FACTOR
C   PVFC         =  PRESENT VALUE OF NUCLEAR FUEL COSTS IN DOLLARS
C   PWF(X,T)     =  PRESENT WORTH FACTOR AT RATE X FOR T YEARS
C   R            =  EFFECTIVE INCOME TAX RATE
C   RFR(I)       =  CONVENTIONAL TANKER FLEET RFR FOR YEAR (I)  ($/BBL)
C   SAS          =  FIRST YEAR COST OF STORES AND SUPPLIES
C   SCH          =  CAPITALIZED COST OF HULL IN DOLLARS (PRESENT VALUE)
C   SCRN         =  CAPITALIZED COST OF NSSS IN DOLLARS (PRESENT VALUE)
C   SD           =  NUMBER OF DAYS AT SEA PER YEAR
C   SHP          =  TOTAL RATED SHAFT HORSEPOWER
C   SHPHYR       =  TOTAL SHAFT HORSEPOWER HOURS PER YEAR
C   SIBI         =  INITIAL BASELINE INSPECTION COST IN DOLLARS
C   SICT         =  INITIAL CREW TRAINING COST IN DOLLARS
C   SIMIS        =  SHIP PREDELIVERY CHARGES IN DOLLARS
```

```
C  SL              =  SHIP LIFE IN YEARS
C  STCC            =  CAPITALIZED COST OF SHIP CONSTRUCTION IN DOLLARS
C                     (PRESENT VALUE)
C  STOC            =  PRESENT VALUE OF TOTAL OPERATING COSTS IN DOLLARS
C  SUBRFR          =  NORTHERN TERMINAL TO MOBILE TERMINAL RFR ($/BBL)
C  TAOC(I)         =  TOTAL ANNUAL OPERATING COST FOR YEAR (I) IN DOLLARS
C  TERM            =  BUDGETARY ESTIMATE FOR TERMINALS IN DOLLARS PER SHIP
C  TERMC           =  CAPITALIZED COST OF TERMINALS IN DOLLARS PER SHIP
C  TPH             =  TIME IN YEARS BEFORE DELIVERY THAT PROGRESS PAYMENTS
C                     FOR THE HULL BEGIN
C  TPRN            =  TIME IN YEARS BEFORE DELIVERY THAT PROGRESS PAYMENTS
C                     FOR THE NSSS BEGIN
C  TPT             =  TIME IN YEARS BEFORE DELIVERY THAT PROGRESS PAYMENTS
C                     FOR THE TERMINALS BEGIN
C  TRFR            =  TOTAL TRANSPORTATION SYSTEM RFR ($/BBL)
C  X               =  INDIRECT OR EFFECTIVE COST OF MONEY
      REAL*8 SCH,PVFC,TERMC,STOC,CAOC,SCRN,CAPS,TAOC(25),AAC,AFC(25),SHP
     2HYR,CAPT,SUBRFR,CONRFR,STCC,PRFR,RFR(25),X,CRFT,CRFTT,NOBBL,TRFR,A
     3AOC
      REAL T,AI
      CRF(X,T)=X/(1.0-(1.0+X)**(-T))
      PWF(X,T)=(1.0+X)**(-T)
      ACC=2911019.
      AVD=325.72
      B=.75
      BBLVOY=1828849.
      BI=.09
      CATR=275880.
      CH=245000000.
      CISI=108000.
      CRFR=1.88
      CRFU=3700000.
      CRN=200000000.
      CSHPHR=.0116
      DPVOY=16.84
```

```
DT=25.
DTT=35.
ECCISI=.08
ECCRFU=.08
ECESS=.08
ECL=.06
ECMAR=.08
ECMIS=.08
ECNF=.075
ECON=.03925
ECRFR=.08
ECSAS=.08
ECVE=.08
ER=.12
ERX=.03925
ESS=88500.
HAM=5006250.
MAR=1950000.
MIS=965000.
NLI=1150000.
PAI=312314.
PU=.9
R=.616364
SAS=600000.
SD=297.04
SHP=240000.
SICT=1379400.
SIBI=653000.
SIMIS=1261594.
SL=25.
TERM=76817000.
TERMO=4568000.
TPH=-5.25
TPRN=-3.5
TPT=-5.25
```

```
      X=BI*B+ER*(1.0-B)-BI*B*R
      SCH=0.0
      DO 2 I=1,12
      SCH=CH*.075*PWF(X,TPH)+SCH
      CH=CH*(1.0+ECON)
      TPH=TPH+.5
      IF(TPH.GT.0.0)TPH=0.0
    2 CONTINUE
      TPH=1.0
      SCH=SCH+.1*CH*PWF(X,TPH)
      SCRN=0.0
      DO 3 I=1,8
      SCRN=SCRN+.1125*CRN*PWF(X,TPRN)
      CRN=CRN*(1.0+ERX)
      TPRN=TPRN+.5
    3 CONTINUE
      TPRN=2.
      SCRN=SCRN+.1*CRN*PWF(X,TPRN)
      STCC=SCH+SCRN
      TERMC=0.0
      DO 4 I=1,12
      TERMC=TERM*.0750*PWF(X,TPT)+TERMC
      TERM=TERM*(1.0+ECON)
      TPT=TPT+.5
      IF(TPT.GT.0.0)TPT=0.0
    4 CONTINUE
      TPT=1.0
      TERMC= TERMC+.1*TERM*PWF(X,TPT)
      N=25.
      PVFC=0.0
      STOC=0.0
      PRFR=0.0
      DO 5 I=1,N
      AI=I
      SHPHYR=SHP*PU*SD*24.
```

```
      AFC(I)=CSHPHR*SHPHYR
      PVFC=PVFC+AFC(I)*PWF(X,AI)
      CSHPHR=CSHPHR*(1.0+ECNF)
      TAOC(I)=(ACC+PAI+HAM+MIS+TERMO+NLI+ESS+SAS+CISI+CRFU+CATR+MAR)
      STOC=STOC+TAOC(I)*PWF(X,AI)
      RFR(I)=CRFR
      PRFR=PRFR+RFR(I)*PWF(X,AI)
      CRFR=CRFR*(1.0+ECRFR)
      ACC=ACC*(1.0+ECL)
      TERMO=TERMO*(1.0+ECVE)
      MAR=MAR*(1.0+ECMAR)
      MIS=MIS*(1.0+ECMIS)
      ESS=ESS*(1.0+ECESS)
      SAS=SAS*(1.0+ECSAS)
      CISI=CISI*(1.0+ECCISI)
      CRFU=CRFU*(1.0+ECCRFU)
    5 CONTINUE
      CAOC=PVFC+STOC
      CRFT=(CRF(X,DT)-R/DT)/(1.0-R)
      CAPS=(STCC+SICT+SIBI+SIMIS)*CRFT
      CRFTT=(CRF(X,DTT)-R/DTT)/(1.0-R)
      CAPT=TERMC*CRFTT
      AAC=CAOC*CRF(X,SL)+CAPS+CAPT
      AAOC=AAC-(CAPS+CAPT)
      CONRFR=PRFR*CRF(X,SL)
      NOBBL=(AVD/DPVOY)*BBLVOY
      SUBRFR=AAC/NOBBL
      TRFR=SUBRFR+CONRFR
      WRITE(6,600)
      WRITE(6,601)
      WRITE(6,602)
      WRITE(6,603) TRFR,SUBRFR,CONRFR,AAC,AAOC,CAPS,CAPT
  600 FORMAT(' ',9X,'SYSTEM',7X,'ICEBKR.',7X,'CONV.',7X,'TOT. AVER.',7X,
     2'AVER. ANN.',7X,'AVER. ANN. CAP.',7X,'AVER. ANN. CAP.')
  601 FORMAT(' ',10X,'RFR',11X,'RFR',10X,'RFR',8X,'ANN. COST',8X,'OPER.
```

```
      2COST',10X,'COST-SHIP',13X,'COST-TERM')
  602 FORMAT('+',8X,'________',5X,'_________',5X,'_______',5X,'________
     2___',5X,'____________',5X,'_________________',5X,'_______________
     3_')
  603 FORMAT(' ',10X,F5.2,9X,F4.2,9X,F4.2,7X,1PD11.4,6X,1PD11.4,8X,1PD11
     2.4,11X,1PD11.4)
      STOP
      END
```

APPENDIX B

COMPUTER CODE

ECONOMIC ANALYSIS

FOSSIL FUELED ICEBREAKING

TANKER TRANSPORTATION SYSTEM

REFERENCE CASE PROGRAM

```
C  THIS PROGRAM COMPUTES THE REQUIRED FREIGHT RATE FOR AN ARCTIC ICEBREAK
C  ING TANKER TRANSPORTATION SYSTEM WHICH UTILIZES A FOSSIL FUELED
C  ICEBREAKING TANKER FLEET, A MOBILE TRANSSHIPMENT TERMINAL AND A
C  CONVENTIONAL SURFACE TANKER FLEET TO TRANSPORT CRUDE OIL FROM THE
C  ALASKAN NORTH SLOPE TO THE EAST COAST OF THE UNITED STATES.
C
C  AAC             =  TOTAL AVERAGE ANNUAL COST OF ICEBREAKING TANKER AND
C                     TERMINALS IN DOLLARS
C  AAOC            =  AVERAGE ANNUAL OPERATING COST
C  ACC             =  ANNUAL CREW COST IN DOLLARS
C  AFC(I)          =  ANNUAL FUEL COST FOR YEAR (I) IN DOLLARS
C  AVD             =  SHIP AVAILABILITY IN DAYS PER YEAR
C  B               =  DEBT TO TOTAL CAPITAL RATIO
C  BBLVOY          =  NUMBER OF BARRELS OF CRUDE OIL CARRIED PER VOYAGE
C  BI              =  BANK OR BOND INTEREST RATE
C  CAOC            =  CUMULATIVE ANNUAL OPERATING COSTS (PRESENT VALUE OF
C                     FUEL PLUS OPERATING COSTS) IN DOLLARS
C  CAPS            =  AVERAGE ANNUAL SHIP ACQUISITION COSTS IN DOLLARS
C  CAPT            =  AVERAGE ANNUAL TERMINAL ACQUISITION COSTS IN DOLLARS
C  CF              =  CONVERSION FACTOR (BBL BUNKER C PER POUND)
C  CH              =  BUDGETARY ESTIMATE FOR HULL COST IN DOLLARS
C  CONRFR          =  AVERAGE ANNUAL RFR FOR CONVENTIONAL TANKERS ($/BBL)
C  CPBBL           =  COST OF BUNKER C FUEL OIL IN DOLLARS PER BARREL
C  CPP             =  BUDGETARY ESTIMATE FOR PROPULSION PLANT IN DOLLARS
C  CRFR            =  FIRST YEAR RFR FOR CONVENTIONAL TANKER FLEET ($/BBL)
C  CRF(X,T)        =  CAPITAL RECOVERY FACTOR AT RATE X FOR T YEARS
C                     BEFORE TAXES
C  CRFT(X,DT)      =  CAPITAL RECOVERY FACTOR AT RATE X FOR DT YEARS
C                     AFTER TAXES
C  CRFTT(X,DTT)    =  CAPITAL RECOVERY FACTOR AT RATE X FOR DTT YEARS
C                     AFTER TAXES
C  DPVOY           =  NUMBER OF DAYS PER VOYAGE INCLUDING TURNAROUND TIME
C  DT              =  TIME IN YEARS OVER WHICH THE SHIP IS DEPRECIATED
C  DTT             =  TIME IN YRS OVER WHICH THE TERMINALS ARE DEPRECIATED
C  ECF             =  ESCALATION RATE FOR COST OF BUNKER C
```

```
C  ECL        =  ESCALATION RATE FOR COST OF LABOR
C  ECMAR      =  ESCALATION RATE FOR COST OF MAINTENANCE AND REPAIR
C  ECMIS      =  ESCALATION RATE FOR COST OF MISCELLANEOUS EXPENSES
C  ECON       =  ESCALATION RATE FOR COST OF CONSTRUCTION
C  ECSAS      =  ESCALATION RATE FOR COST OF STORES AND SUPPLIES
C  ECVE       =  ESCALATION RATE FOR COST OF TERMINAL OPERATIONS
C  ER         =  EQUITY RETURN RATE
C  FCR        =  FUEL CONSUMPTION RATE IN POUNDS PER SHP HOUR
C  HAM        =  ANNUAL COST FOR HULL AND MACH. INSURANCE IN DOLLARS
C  MAR        =  FIRST YEAR COST OF MAINTENANCE AND REPAIR IN DOLLARS
C  MIS        =  FIRST YEAR COST OF MISCELLANEOUS EXPENSES IN DOLLARS
C  NOBBL      =  NUMBER OF BARRELS OF CRUDE OIL CARRIED PER YEAR
C  PAI        =  ANNUAL COST OF PROT. AND INDEM. INSURANCE IN DOLLARS
C  PRFR       =  PRESENT VALUE OF CONVENTIONAL TANKER RFR ($/BBL)
C  PU         =  PLANT UTILIZATION FACTOR
C  PVFC       =  PRESENT VALUE OF FOSSIL FUEL COSTS IN DOLLARS
C  PWF(X,T)   =  PRESENT WORTH FACTOR AT RATE X FOR T YEARS
C  R          =  EFFECTIVE INCOME TAX RATE
C  RFR(I)     =  CONVENTIONAL TANKER FLEET RFR FOR YEAR (I) ($/BBL)
C  SAS        =  FIRST YEAR COST OF STORES AND SUPPLIES
C  SCH        =  CAPITALIZED COST OF HULL IN DOLLARS (PRESENT VALUE)
C  SCPP       =  CAPITALIZED COST OF PROPULSION PLANT IN DOLLARS
C                (PRESENT VALUE)
C  SD         =  NUMBER OF DAYS AT SEA PER YEAR
C  SHP        =  TOTAL RATED SHAFT HORSEPOWER
C  SHPHYR     =  TOTAL SHAFT HORSEPOWER HOURS PER YEAR
C  SIMIS      =  SHIP PREDELIVERY CHARGES IN DOLLARS
C  SL         =  SHIP LIFE IN YEARS
C  STCC       =  CAPITALIZED COST OF SHIP CONSTRUCTION IN DOLLARS
C                (PRESENT VALUE)
C  STOC       =  PRESENT VALUE OF TOTAL OPERATING COSTS IN DOLLARS
C  SUBRFR     =  NORTHERN TERMINAL TO MOBILE TERMINAL RFR ($/BBL)
C  TAOC(I)    =  TOTAL ANNUAL OPERATING COST FOR YEAR (I) IN DOLLARS
C  TERM       =  BUDGETARY ESTIMATE FOR TERMINALS IN DOLLARS PER SHIP
C  TERMC      =  CAPITALIZED COST OF TERMINALS IN DOLLARS PER SHIP
```

```
C  TPH            =  TIME IN YEARS BEFORE DELIVERY THAT PROGRESS PAYMENTS
C                    FOR THE HULL BEGIN
C  TPP            =  TIME IN YEARS BEFORE DELIVERY THAT PROGRESS PAYMENTS
C                    FOR THE PROPULSION PLANT BEGIN
C  TPT            =  TIME IN YEARS BEFORE DELIVERY THAT PROGRESS PAYMENTS
C                    FOR THE TERMINALS BEGIN
C  TRFR           =  TOTAL TRANSPORTATION SYSTEM RFR ($/BBL)
C  X              =  INDIRECT OR EFFECTIVE COST OF MONEY

      REAL*8 SCH,PVFC,TERMC,STOC,CAOC,CAPS,TAOC(25),AAC,AFC(25),SHPHYR,C
     2APT,SUBRFR,CONRFR,STCC,PRFR,RFR(25),SCPP,CRF,CRFT,CRFTT,NOBBL,TRFR
     3,X,AAOC
      REAL T,AI
      CRF(X,T)=X/(1.0-(1.0+X)**(-T))
      PWF(X,T)=(1.0+X)**(- T)
      ACC=2146574.
      AVD= 332.92
      B=.75
      BBLVOY=1654013.
      BI=.09
      CF= .0029586
      CH=245000000.
      CPBBL= 21.57
      CPP=30000000.
      CRFR= 1.88
      DPVOY=16.84
      DT=25.
      DTT=35.
      ECF= .075
      ECL=.06
      ECMAR=.08
      ECMIS=.08
      ECON=.03925
      ECRFR= .08
      ECSAS=.08
```

```
      ECVE=.08
      ER=.12
      FCR= .477
      HAM=3093750.
      MAR=1465000.
      MIS=940000.
      PAI=312314.
      PU=.9
      R=.616364
      SAS=600000.
      SD=303.38
      SHP=240000.
      SIMIS=411426.
      SL=25.
      TERM=76817000.
      TERMO=4568000.
      TPH=-3.5
      TPP=-3.5
      TPT=-5.25
      X=BI*B+ER*(1.0-B)-BI*B*R
      SCH=0.0
      DO 1 I=1,8
      SCH=CH*.1125*PWF(X,TPH)+SCH
      CH=CH*(1.0+ECON)
      TPH=TPH+.5
    1 CONTINUE
      TPH=1.0
      SCH=SCH+.1*CH*PWF(X,TPH)
      SCPP=0.0
      DO 2 I=1,8
      SCPP=SCPP+.1125*CPP*PWF(X,TPP)
      CPP=CPP*(1.0+ECON)
      TPP=TPP+.5
    2 CONTINUE
      TPP=2.0
```

```
      SCPP=SCPP+.1*CPP*PWF(X,TPP)
      STCC=SCH+SCPP
      TERMC=0.0
      DO 3 I=1,12
      TERMC=TERM*.075*PWF(X,TPT)+TERMC
      TERM=TERM*(1.0+ECON)
      TPT=TPT+.5
      IF(TPT.GT.0.0) TPT=0.0
    3 CONTINUE
      TPT=1.0
      TERMC=TERMC+.1*TERM*PWF(X,TPT)
      STOC=0.0
      PRFR=0.0
      N=25.
      PVFC=0.0
      DO 4 I=1,N
      AI=I
      SHPHYR=SHP*PU*SD*24.0
      AFC(I)=SHPHYR*FCR*CF*CPBBL
      PVFC=PVFC+AFC(I)*PWF(X,AI)
      CPBBL=CPBBL*(1.0+ECF)
      TAOC(I)=(ACC+PAI+HAM+MIS+TERMO+SAS+MAR)
      STOC=STOC+TAOC(I)*PWF(X,AI)
      RFR(I)=CRFR
      PRFR=PRFR+RFR(I)*PWF(X,AI)
      CRFR=CRFR*(1.0+ECRFR)
      ACC=ACC*(1.0+ECL)
      TERMO=TERMO*(1.0+ECVE)
      MAR=MAR*(1.0+ECMAR)
      MIS=MIS*(1.0+ECMIS)
      SAS=SAS*(1.0+ECSAS)
    4 CONTINUE
      CAOC=PVFC+STOC
      CRFT=(CRF(X,DT)-R/DT)/(1.0-R)
      CAPS=(STCC+SIMIS)*CRFT
```

```
      CRFTT=(CRF(X,DTT)-R/DTT)/(1.0-R)
      CAPT=TERMC*CRFTT
      AAC=CAOC*CRF(X,SL)+CAPS+CAPT
      AAOC=AAC-(CAPS+CAPT)
      CONRFR=PRFR*CRF(X,SL)
      NOBBL=(AVD/DPVOY)*BBLVOY
      SUBRFR=AAC/NOBBL
      TRFR=SUBRFR+CONRFR
      WRITE(6,600)
      WRITE(6,601)
      WRITE(6,602)
      WRITE(6,603)TRFR,SUBRFR,CONRFR,AAC,AAOC,CAPS,CAPT
600   FORMAT(' ',9X,'SYSTEM',7X,'ICEBKR.',7X,'CONV.',7X,'TOT. AVER.',7X,
     2'AVER. ANN.',7X,'AVER. ANN. CAP.',7X,'AVER. ANN. CAP.')
601   FORMAT(' ',10X,'RFR',11X,'RFR',10X,'RFR',8X,'ANN. COST',8X,'OPER.
     2COST',10X,'COST-SHIP',13X,'COST-TERM')
602   FORMAT('+',8X,'________',5X,'_________',5X,'_______',5X,'_________
     2___',5X,'____________',5X,'_________________',5X,'________________
     3_')
603   FORMAT(' ',10X,F5.2,9X,F4.2,9X,F4.2,6X,1PD11.4,6X,1PD11.4,9X,1PD11
     2.4,11X,1PD11.4)
      STOP
      END
```

Thesis
P7445
c.1
Porter
187424
Economic analysis of an Arctic icebreaking tanker transportation system: nuclear vs. fossil.